TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY PROGRAM FOR CONSUMER PRODUCTS AND COMMERCIAL AND INDUSTRIAL EQUIPMENT:

MISCELLANEOUS REFRIGERATION PRODUCTS

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EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

ES.1 OVERVIEW OF PRELIMINARY ANALYSIS ACTIVITIES

The Energy Policy and Conservation Act, as amended ("EPCA")[a] (42 U.S.C. 6291-6317), among other things, authorizes DOE to regulate the energy efficiency of a number of consumer products and industrial equipment. Title III, Part B[b] of EPCA established the Energy Conservation Program for Consumer Products Other Than Automobiles, which, in addition to identifying particular consumer products and commercial equipment as covered under the statute, permits the Secretary of Energy to classify additional types of consumer products as covered products. (42 U.S.C. 6292(a)(20)) DOE added miscellaneous refrigeration products ("MREFs") as covered products through a final determination of coverage published in the *Federal Register* on July 18, 2016 (the "July 2016 Final Coverage Determination"). 81 FR 46768. MREFs are consumer refrigeration products other than refrigerators, refrigerator-freezers, or freezers. (10 CFR 430.2) MREFs include refrigeration products such as coolers (*e.g.*, wine chillers and other specialty products) and combination cooler refrigeration products (*e.g.*, wine chillers and other specialty compartments combined with a refrigerator, refrigerator-freezer, or freezer).

When establishing new or amended standards for a covered product DOE must follow specific statutory criteria. EPCA requires that any new or amended energy conservation standard be designed to achieve the maximum improvement in energy or water efficiency that is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) On December 8, 2020, DOE published a notice that it was initiating an early assessment review to determine whether any new or amended standards would satisfy the relevant requirements of EPCA for a new or amended energy conservation standard for MREFs and a request for information (the "December 2020 EA RFI"). 85 FR 78964. DOE is currently evaluating potential amendments to the energy conservation standards for MREFs. This technical support document ("TSD") presents preliminary analyses in support of that process. This executive summary presents key results of those analyses and delineates issues on which DOE seeks comment.

Figure ES.1.1 presents a summary of the analytical components of the standards-setting process and illustrates how key results are generated. The focal point of the figure is the center column, labeled "Analyses." The columns labeled "Key Inputs" and "Key Outputs" show how the analyses fit into the process and how they relate to each other. Key inputs are the types of data and other information that the analyses require. Some key information is obtained from public databases; DOE collects other inputs from interested parties or persons having special knowledge and expertise. Key outputs are analytical results that feed directly into the standards-setting process. The issues on which DOE seeks comment from interested parties derive from the key results that are generated by the preliminary analysis. Arrows connecting analyses show the types of information that feed from one analysis to another.

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[a] All references to EPCA in this document refer to the statute as amended through the Energy Act of 2020, Public Law 116-260 (Dec. 27, 2020).
[b] For editorial reasons, upon codification in the U.S. Code, Part B was redesignated Part A.

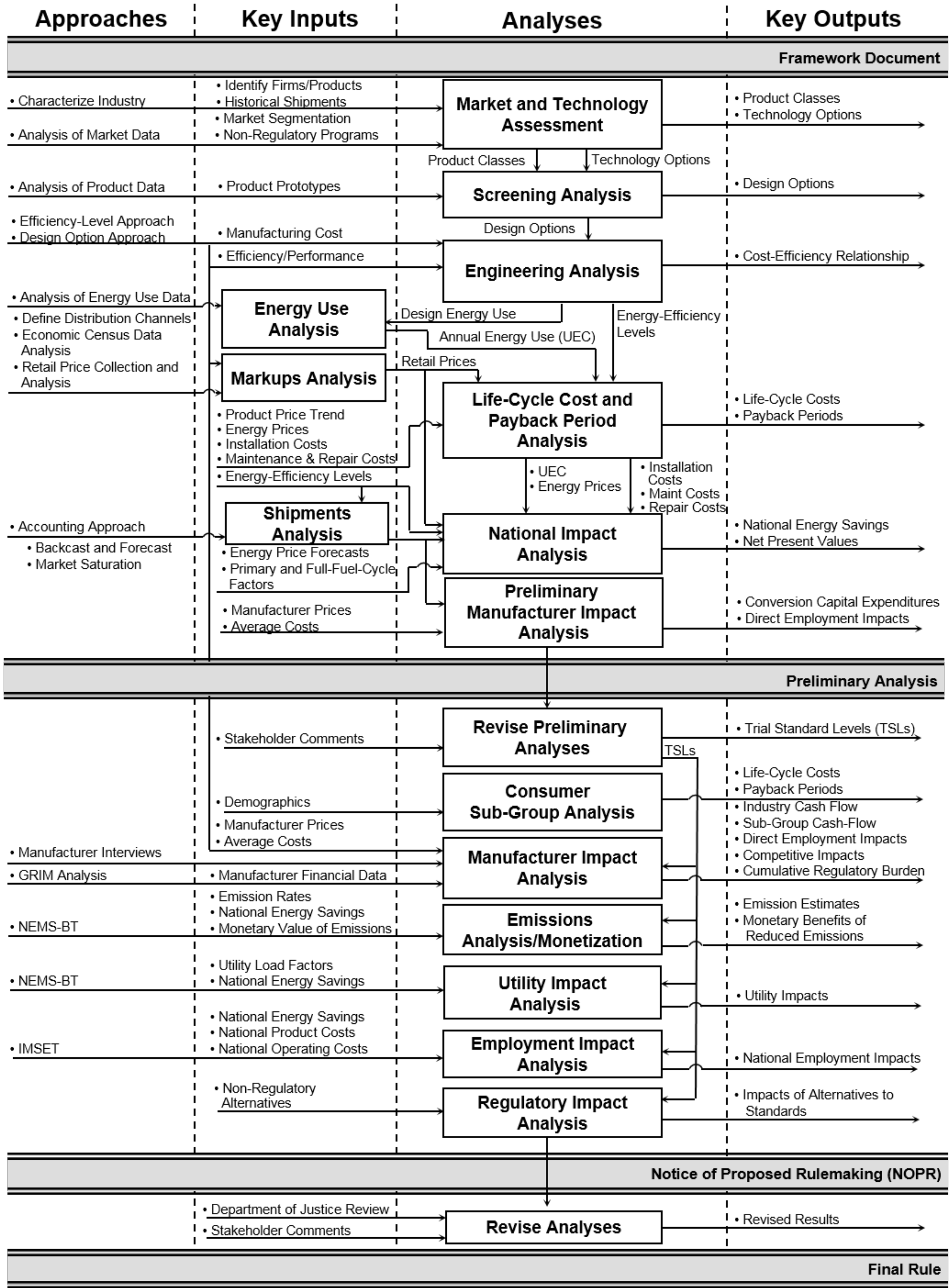

Figure ES.1.1 Flow Diagram of Analyses for the MREFs Rulemaking Process

ES.2 KEY RESULTS OF THE ANALYSIS

ES.2.1 Market and Technology Assessment

When initiating an analysis of potential energy conservation standards for consumer products, DOE obtains information on the present and past industry structure and market characteristics for the products concerned. DOE assesses industries and products both quantitatively and qualitatively, based on publicly available information.

For this preliminary analysis, DOE addressed: (1) MREF manufacturers, (2) existing regulatory and non-regulatory initiatives for improving product efficiency, and (3) trends in product characteristics. These data and resource material were used throughout the analysis.

DOE reviewed available public literature and relied on information gathered during the previous MREF energy conservation standards rulemaking to develop an overall understanding of the MREF industry in the United States. In particular, DOE sought information on: (1) manufacturers, (2) product information, and (3) industry trends. Chapter 3 of the preliminary TSD describes the market analysis and resulting information.

DOE typically uses information about existing and past technology options and working prototype designs to determine which technologies and combinations of technologies manufacturers may use to attain higher performance levels. As part of the market and technology assessment, DOE develops a list of technologies to be considered.

DOE developed a list of MREF technologies from previous rulemaking information, trade publications, technical papers, manufacturer literature, component manufacturer literature, and stakeholder comments in response to the December 2020 EA RFI. Because existing products contain many technologies for improving product efficiency, product literature and direct examination provided additional information.

ES.2.2 Screening Analysis

The screening analysis (chapter 4 of the preliminary TSD) examines whether technologies identified in the technology assessment: (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on product utility or availability; (4) have adverse impacts on health and safety; and/or (5) use proprietary technologies. Technologies not meeting these five criteria are screened from further consideration in the analysis. In the subsequent engineering analysis, DOE further examined the technology options that it did not remove from consideration in the screening analysis.

ES.2.3 Engineering Analysis

The engineering analysis (chapter 5 of the preliminary TSD) establishes the relationship between the costs of manufacturing MREFs and their efficiencies. These relationships serve as the basis for calculating costs and benefits of modified product designs for consumers, manufacturers, and the nation. Chapter 5 describes the product classes DOE analyzed, the efficiency levels DOE analyzed, the methodology DOE used to develop the manufacturing production costs and energy use estimates, and the cost-efficiency results.

ES.2.3.1 Product Classes Analyzed

When evaluating and establishing energy conservation standards, DOE may divide covered products into product classes by the type of energy used, or by capacity or other performance-related features that justify a different standard. (42 U.S.C. 6295(q)) In making a determination whether capacity or another performance-related feature justifies a different standard, DOE must consider such factors as the utility of the feature to the consumer and other factors DOE deems appropriate. (*Id.*)

For MREFs, the current energy conservation standards specified in 10 CFR 430.32(aa) are based on 12 product classes determined according to the following performance-related features that provide utility to the consumer: type of unit (cooler or combination cooler refrigeration product), total refrigerated volume (standard or compact), presence of an automatic icemaker, intended installation (*i.e.*, built-in or freestanding), and compartment types.

For the preliminary engineering analysis, DOE directly analyzed three product classes that represent the majority of industry shipments for MREFs. DOE did not directly analyze all covered product classes in order to carry out the analysis as efficiently as possible. Additionally, the analysis of the directly analyzed classes is intended to be representative of similar product classes. For instance, the analysis for freestanding compact coolers is also representative of the cost-efficiency characteristics of built-in compact coolers. For combination cooler product classes, which have refrigerator or freezer compartments, DOE relied on information from its preliminary engineering analysis for refrigerators, refrigerator-freezers, and freezers.[c] Within each product class, DOE also selected one or more volumes for the analysis to best represent the range of products available in that product class.

Table ES.2.1 summarizes the analyzed product classes, including the representative volumes used as the basis for the engineering analysis.

Table ES.2.1 Evaluated MREF Product Classes

Product Class	Description	Adjusted Volume(s) (cubic feet)
Cooler-FC	Freestanding compact coolers	3.1, 5.1
Cooler-F	Freestanding coolers	15.3
C-13A	Compact cooler with all-refrigerator—automatic defrost	5.1

[c] On October 15, 2021, DOE published a notice regarding its preliminary analysis to consider energy conservation standards for refrigerators, refrigerator-freezers, and freezers (the “2021 RFs Preliminary Analysis”). 86 FR 57378. The TSD for this analysis is found at https://www.regulations.gov/docket/EERE-2017-BT-STD-0003/document.

ES.2.3.2 Efficiency Levels Defined

DOE based its preliminary analysis for MREFs on the current annual energy use metric for these products as determined by the existing DOE test procedure.

For analyzed product classes, DOE selects a baseline model as a reference point against which any changes resulting from energy conservation standards can be measured. The baseline model in each product class represents the characteristics of common or typical products in that class. Typically, a baseline model is one that just meets the current minimum energy conservation standards by a small margin. For this rulemaking, DOE chose baseline efficiency levels for each product class and analyzed volume based on the current Federal energy conservation standards, expressed as maximum annual energy consumption (in kilowatt-hours per year ("kWh/yr")) as a function of the product's adjusted volume ("AV," in cubic feet ("ft^3")).

DOE also considered five higher efficiency levels for each analyzed product class of coolers, including a maximum technologically feasible level. For combination coolers, DOE considered four higher efficiency levels, including a maximum technologically feasible level. DOE expressed these efficiency levels as a percentage energy use reduction compared to the baseline for that product class.

DOE developed efficiency levels beyond the baseline using a combination of: (1) relying on observed efficiency levels in the market (*i.e.*, the efficiency-level approach), or (2) determining the incremental efficiency improvements associated with incorporating specific design options to a baseline model (*i.e.*, the design-option approach). For the efficiency-level approach, DOE relied on the range of efficiencies of products currently on the market to identify relevant efficiency levels based on market availability (*e.g.*, ENERGY STAR and maximum available efficiencies). For the design-option approach, DOE relied on energy use modeling to estimate the performance of designs not observed during product teardowns.

Table ES.2.2 and Table ES.2.3 summarize the efficiency levels DOE considered in this preliminary analysis for each analyzed product class and AV.

Table ES.2.2 Efficiency Levels for Analyzed Coolers (% Energy Use Less than Baseline)

Product Class (AV, ft^3)	**Cooler-FC (3.1)**	**Cooler-FC (5.1)**	**Cooler-F (15.3)**
EL 1	20% †	20% †	10% †
EL 2	30% ‡	30% ‡	20%
EL 3	45%	49%	30% ‡
EL 4	50%	50%	35%
EL 5 – Max Tech	51%	52%	39%

† Minimally meets the ENERGY STAR levels for freestanding products.
‡ Minimally meets the ENERGY STAR levels for built-in products.

Table ES.2.3 Efficiency Levels for Analyzed Combination Coolers (% Energy Use Less than Baseline)

Product Class (AV, ft^3)	C-13A (5.1)
EL 1	10%
EL 2	19%
EL 3	24%
EL 4 – Max Tech	27%

Chapter 5 of this preliminary TSD includes additional details on how DOE developed the efficiency levels for its analysis.

ES.2.3.3 Manufacturer Production Costs

For this preliminary analysis, DOE relied on physical teardowns and catalog teardowns to determine the manufacturer production cost ("MPC") required to achieve higher efficiency levels. These approaches are described as follows:

- Physical teardowns: Under this approach, DOE physically dismantles a commercially available product, component-by-component, to develop a detailed bill of materials for the product.
- Catalog teardowns: In lieu of physically deconstructing a product, DOE identifies each component using parts diagrams (available from manufacturer websites or appliance repair websites, for example) to develop the bill of materials for the product.

In addition to the directly analyzed models, DOE estimated costs for the various components incorporated into higher efficiency MREFs. Chapter 5 of the preliminary TSD includes information on the inputs used to determine the incremental MPCs.

DOE's engineering analysis produced cost-efficiency curves for each product class and volume analyzed. The cost-efficiency curves describe the estimated increase in MPC required to improve a baseline-efficiency product to each of the considered efficiency levels. Table ES.2.4 and Table ES.2.5 present the results of the engineering analysis for MREFs.

Table ES.2.4 Incremental Manufacturer Production Cost Results for Coolers

Product Class (AV, ft^3)	Cooler-FC (3.1)	Cooler-FC (5.1)	Cooler-F (15.3)
EL 1 (%—Cost)	20% – $5.59	20% – $6.36	10% – $16.55
EL 2 (%—Cost)	30% – $48.50	30% – $9.97	20% – $59.12
EL 3 (%—Cost)	45% – $113.98	49% – $34.36	30% – $106.02
EL 4 (%—Cost)	50% – $166.57	50% – $135.83	35% – $266.38
EL 5 – Max Tech (%—Cost)	51% – $184.43	52% – $155.07	39% – $324.37

Table ES.2.5 Incremental Manufacturer Production Cost Results for Combination Coolers

Product Class (AV, ft^3)	C-13A (5.1)
EL 1 (%—Cost)	10% – $2.21
EL 2 (%—Cost)	19% – $4.61
EL 3 (%—Cost)	24% – $72.82
EL 4 – Max Tech (%—Cost)	27% – $127.07

ES.2.4 Markups Analysis

DOE developed appropriate markups (*e.g.,* retailer markups, distributor markups, contractor markups) in the distribution chain to convert the MPCs estimated in the engineering analysis to consumer prices, which then were used in the life-cycle cost ("LCC") and payback period ("PBP") analyses.

As a first step, DOE converted the MPC to the manufacturer selling price ("MSP") by applying a manufacturer markup. The MSP is the price the manufacturer charges its first customer when selling into the product distribution channels. For this preliminary analysis, DOE used a manufacturer markup of 1.25 for freestanding compact coolers and 1.41 for all other MREF product classes, consistent with the analysis in the previous rulemaking.[d]

DOE further developed baseline and incremental markups for each actor in the distribution chain (after the product leaves the manufacturer). DOE identified two distribution channels through which MREFs move from manufacturers to consumers. In the first distribution channel, manufacturers sell the products directly to retailers, who then sell to consumers. In the second distribution channel, manufacturers sell the products to wholesalers, who in turn sell the products to dealers or retailers, and then to consumers. DOE used the same split between the retailer and wholesaler-to-contractor distribution channel as estimated in the October 2016 Direct Final Rule (81 FR 75194) for each product class.

[d] See Table 6.2.1 of the MREF Direct Final Rule TSD, available at: www.regulations.gov/document/EERE-2011-BT-STD-0043-0118 (Last accessed on August 31, 2021).

DOE developed baseline and incremental markups for each market player in the two distribution channels using (1) 2017 U.S. Census *Annual Retail Trade Survey (ARTS)* for electronics and appliance stores, and (2) 2017 U.S. Census *Annual Wholesale Trade Report (AWTR)* for household appliances and electrical and electronic goods merchant wholesale sector. Lastly, DOE applied state and local sales tax to derive the final consumer purchase prices for MREFs. Table ES.2.6 summarizes the national average markups at each stage in the distribution channel and the average sales tax. Chapter 6 of this preliminary TSD provides a detailed discussion of the markups analysis.

Table ES.2.6 Summary of Markups for MREFs

Markup	Manufacturer → Retailer → Consumer		Manufacturer → Wholesaler → Retailer → Consumer	
	Baseline Markup	**Incremental Markup**	**Baseline Markup**	**Incremental Markup**
Manufacturer	1.25/1.41		1.25/1.41	
Wholesaler	-	-	1.35	1.20
Retailer	1.49	1.24	1.49	1.24
Sales Tax	1.073		1.073	

ES.2.5 Energy Use Analysis

The purpose of the energy use analysis is to determine the annual energy consumption of MREFs and to assess the energy savings potential of more stringent standards. The energy use analysis provides the basis for developing the energy savings used in the LCC and subsequent analyses. For each volume and considered efficiency level, DOE derived the energy consumption as measured by the DOE test procedure for MREFs.

Table ES.2.7 shows the average annual energy use of MREFs in each of the product classes at each EL that DOE considered in this preliminary analysis and the annual energy savings with respect to the baseline (EL 0). Chapter 7 of this preliminary TSD provides more details on the methods, data sources, and assumptions used for the energy use analysis.

Table ES.2.7 Average Annual Energy Use and Savings for Analyzed Product Classes (kWh/Year)

EL	Cooler-FC *		Cooler-F		C-13A	
	Energy Use	Savings	Energy Use	Savings	Energy Use	Savings
0	183.0	--	276.4	--	223.9	--
1	146.4	36.6	248.7	27.6	201.6	22.4
2	128.1	54.9	221.1	55.3	181.4	42.6
3	99.3	83.8	193.5	82.9	170.2	53.7
4	91.5	91.5	179.6	96.7	163.5	60.5
5	89.3	93.7	168.6	107.8		

*The energy use for MREFs with multiple representative units (3.1 and 5.1 ft^3 adjusted volume) was derived as the estimated market-weighted average energy use across each representative unit.

ES.2.6 Life-Cycle Cost and Payback Period Analyses

The impacts of energy conservation standards on consumers often include a change in operating expense (usually decreased energy expenses) and a change in purchase price (usually increased). The LCC of a product is the cost it incurs over its lifetime, taking into account both purchase price and operating expenses. The PBP represents the time it takes to recover the additional installed cost of the more-efficient products through operating expense savings.

DOE analyzed the net financial effect on consumers of potential standards for MREFs by calculating the LCC and PBP using inputs from the engineering performance data, the markups, and the energy use analyses.

Inputs to the LCC calculation include the installed cost to the consumer, operating expenses, lifetime of the product, and discount rates. DOE examined installation, maintenance, and repair costs for the efficiency levels considered in this preliminary analysis. DOE found that incremental changes in energy efficiency produce no changes in installation, maintenance, or repair costs. Therefore, DOE did not consider such inputs in the LCC and PBP analyses. For electricity prices, DOE used marginal and average prices, which vary by region and sector. DOE estimated these prices using data published with the Edison Electric Institute ("EEI")'s Typical Bills and Average Rates reports for summer and winter 2020 and the methodology provided in a Lawrence Berkeley National Laboratory report. DOE then used projections of the prices from the Energy Information Administration (EIA)'s *Annual Energy Outlook 2021* (*AEO2021*) to estimate future electricity prices.

DOE assumed that the probability function for the annual survival of MREFs would take the form of a Weibull distribution. A Weibull distribution is a probability distribution commonly used to measure failure rates. For this preliminary analysis, DOE retained the assumptions for lifetime used in the October 2016 Direct Final Rule (81 FR 75194). Specifically, DOE assumed a maximum lifetime of 40 years for all product classes and an average lifetime of 10.3 years for compact coolers and 17.4 years for full-size coolers.

To estimate the percentage of consumers who would be affected by a potential standard at each efficiency level, the LCC analysis considered the projected distribution of efficiencies for MREFs purchased under the no-new-standards case. To derive the energy efficiency distribution of MREFs for the assumed compliance year (2029), DOE relied on current model count data from DOE's Compliance Certification Management System ("CCMS")[e] and assumed no changes in MREF efficiency over time. Using the distribution of efficiencies for each representative unit, DOE assigned a specific MREF efficiency to each consumer. If a consumer was assigned a product efficiency that equaled or exceeded the efficiency of the efficiency level under consideration, the LCC calculation showed that the consumer would be unaffected by that standard level.

Table ES.2.8 shows the no-new-standards case efficiency distribution used for each analyzed product class in the assumed compliance year (2029).

Table ES.2.8 Market Share of each Efficiency Level for the No-New-Standards Case in the Compliance Year

Product Class	Total Adjusted Volume (cu. ft.)	2029 Market Share (%)						
		EL 0	EL 1	EL 2	EL 3	EL 4	EL 5	Total*
Cooler-FC	3.1	81.7	9.6	5.3	3.1	0.0	0.3	100.0
	5.1	75.5	14.3	9.8	0.3	0.0	0.0	100.0
Cooler-F	15.3	64.6	24.8	9.7	0.9	0.0	0.0	100.0
C-13A	5.1	100.0	0.0	0.0	0.0	0.0		100.0

* The total may not sum to 100% due to rounding.

Table ES.2.9 through Table ES.2.14 present the key findings from the LCC and PBP analyses. These findings include, for the compliance year: (1) the average LCC of each EL, (2) the average PBP relative to the baseline product (EL 0), (3) average LCC savings that result from a standard set at a given EL, based on the no-new-standards-case and standards-case efficiency distributions, and (4) the share of consumers that would experience a net cost (*i.e.,* negative LCC savings).

[e] Available at: www.regulations.doe.gov/certification-data/products.html#q=Product_Group_s%3A* (Last accessed on April 2, 2021).

Table ES.2.9 LCC and PBP Results by Efficiency Level for Cooler-FC

Efficiency Level	Average Costs (*2020$*)				Simple PBP (*years*)	Average Lifetime (*years*)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Baseline	526.9	27.9	238.3	765.3	--	10.3
1	534.7	23.3	198.5	733.2	1.7	10.3
2	590.5	20.6	176.0	766.5	8.7	10.3
3	686.1	16.2	138.0	824.1	13.6	10.3
4	789.2	15.0	127.5	916.7	20.3	10.3
5	819.8	14.6	124.5	944.3	22.0	10.3

Note: The results for each EL represent the average value if all purchasers in the sample use products with that efficiency level. The PBP is measured relative to the baseline product.

Table ES.2.10 Average LCC Savings for Cooler-FC

Efficiency Level	Average LCC Savings* (*2020$*)	% of Consumers that Experience Net Cost
1	39.7	1%
2	-1.3	56%
3	-60.6	75%
4	-152.0	93%
5	-179.7	94%

* The calculation considers only affected consumers. It excludes purchasers whose purchasing decision would not change under a standard set at the corresponding EL, *i.e.*, those with zero LCC savings.

Table ES.2.11 LCC and PBP Results by EL for Cooler-F

Efficiency Level	Average Costs (*2020$*)				Simple PBP (*years*)	Average Lifetime (*years*)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Baseline	1755.0	42.8	551.8	2306.8	--	17.4
1	1775.9	40.0	515.2	2291.1	7.3	17.4
2	1850.7	36.0	464.2	2314.8	14.1	17.4
3	1942.1	31.6	407.4	2349.6	16.8	17.4
4	2257.8	29.4	378.8	2636.6	37.6	17.4
5	2371.9	27.6	355.9	2727.8	40.7	17.4

Note: The results for each EL represent the average value if all purchasers in the sample use products with that efficiency level. The PBP is measured relative to the baseline product.

Table ES.2.12 Average LCC Savings for Cooler-F

Efficiency Level	Average LCC Savings* (*2020$*)	% of Consumers that Experience Net Cost
1	24.6	19%
2	-9.0	62%
3	-43.1	76%
4	-329.8	97%
5	-421.0	98%

* The calculation considers only affected consumers. It excludes purchasers whose purchasing decision would not change under a standard set at the corresponding EL, *i.e.*, those with zero LCC savings.

Table ES.2.13 LCC and PBP Results by EL for C-13A

Efficiency Level	Average Costs (*2020$*)				Simple PBP (*years*)	Average Lifetime (*years*)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Baseline	1872.3	34.4	292.5	2164.8	--	10.3
1	1875.7	31.7	269.5	2145.1	1.2	10.3
2	1879.6	29.0	246.8	2126.4	1.4	10.3
3	2010.8	27.3	232.1	2242.9	19.6	10.3
4	2115.1	26.3	223.4	2338.4	29.9	10.3

Note: The results for each EL represent the average value if all purchasers in the sample use products with that efficiency level. The PBP is measured relative to the baseline product.

Table ES.2.14 Average LCC Savings for C-13A

Efficiency Level	Average LCC Savings* (*2020$*)	% of Consumers that Experience Net Cost
1	25.4	0%
2	45.7	1%
3	-79.9	90%
4	-177.7	96%

* The calculation considers only affected consumers. It excludes purchasers whose purchasing decision would not change under a standard set at the corresponding EL, *i.e.*, those with zero LCC savings.

Chapter 8 of this preliminary TSD provides a detailed description of the LCC and PBP inputs, analysis, and results.

ES.2.7 Shipments Analysis

Shipments projections are used to calculate the national impacts of standards on energy savings, net present value ("NPV"), and future manufacturer cash flows. DOE used a stock-accounting method to estimate shipments to market segments that contribute to overall product demand.

DOE developed total shipments estimates for each of the analyzed product classes in this preliminary analysis. For coolers, DOE assumed the same product saturation rates as developed in the October 2016 Direct Final Rule (81 FR 75194) and applied them to the projected national housing stocks to derive the stock of in-service cooler products in 2029. DOE then estimated the number of new shipments by combining the estimates of stocks with product lifetime estimates developed in the LCC analysis. For combination cooler refrigeration products, DOE used feedback from manufacturers and available models existing in DOE's CCMS database.

To project future shipments, DOE estimated that shipments would increase in line with the increase in housing stock in the U.S. For coolers, DOE assumed that the saturation rates would remain constant projecting forward to 2056. DOE projected the stock of coolers by multiplying the total number of household estimates from *AEO 2021* forecasts with the product saturations. DOE then determined the shipment projections by dividing the projected stock by the mean product lifetime as developed in the LCC analysis. Shipment projections for combination coolers were estimated by applying the housing stock growth rates derived from *AEO 2021* to the shipment estimates for the compliance year. The housing stock forecast from *AEO 2021* is only available up to 2050; hence, DOE assumed that for projections beyond 2050, growth rates would continue according to the average growth rate between 2040 and 2050. Chapter 9 of this preliminary TSD provides additional details regarding the shipments analysis.

Figure ES.2.1 shows the projected shipments for the no-new-standards case for each analyzed product class.

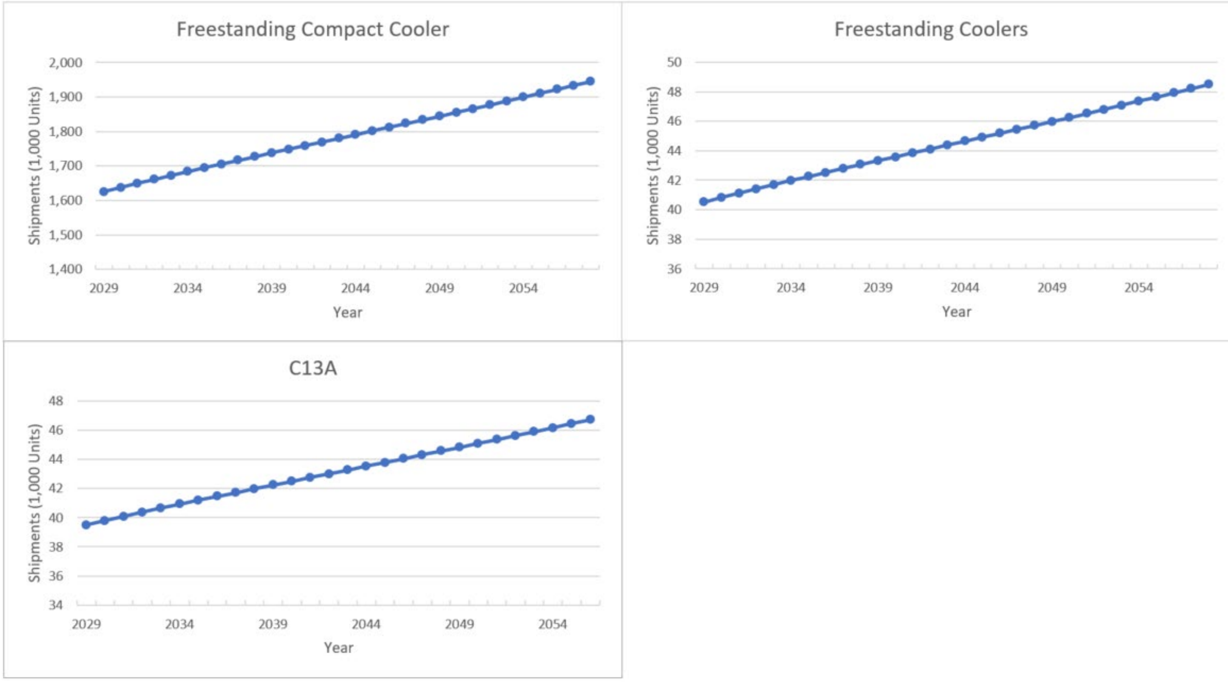

Figure ES.2.1 Projected Shipments for the No-New-Standards Case

ES.2.8 National Impact Analysis

The national impact analysis ("NIA") estimates the following national impacts from possible efficiency levels for MREFs: (1) national energy savings; (2) monetary value of the energy savings due to standards; (3) increased total installed costs of the considered products due to standards; and (4) the NPV of the difference between the value of energy savings and increased total installed costs. DOE prepared spreadsheet models to estimate energy savings and national consumer economic costs and savings resulting from potential standards. In contrast to the LCC and PBP analyses, which use probability distributions for the inputs, the NIA uses average or typical values for inputs.

In its analysis, DOE analyzes the energy and economic impacts of a potential standard on all product classes in the scope of MREFs. Non-representative product classes (*i.e.*, those not analyzed in the engineering, energy-use, and LCC analyses) are calibrated using results for the analyzed product class that best represents each non-representative product class. For example, engineering data from freestanding compact coolers are used to represent built-in compact coolers, as those products are often marketed as both freestanding and built-in. Energy use values of non-representative combination coolers are developed based on information for corresponding product classes from DOE's preliminary engineering analysis for refrigerators, refrigerator-freezers, and freezers. (*See* chapter 5 of the 2021 RFs Preliminary Analysis TSD). DOE assumes the incremental cost between efficiency levels is the same for representative freestanding units and non-representative built-in units. See chapter 10 of this preliminary TSD for more details.

ES.2.8.1 National Energy Savings

DOE calculated annual NES as the difference between national energy consumption in the no-new-standards-case and under a potential standard set at each EL. Cumulative energy savings are the sum of the annual NES over the period in which products shipped in 2029-2058 are in operation. The NES results shown in Table ES.2.15 are expressed as full-fuel cycle energy savings in quads (quadrillion Btu).

Table ES.2.15 Estimates of Cumulative Full-Fuel Cycle National Energy Savings for MREFs (quads)

EL	Compact Coolers (freestanding and built-in)	Coolers (freestanding and built-in)	Combination Coolers	Total*
1	0.13	0.00	0.00	0.14
2	0.21	0.01	0.00	0.23
3	0.36	0.01	0.01	0.39
4	0.41	0.02	0.01	0.43
5	0.42	0.02	0.01	0.45

d*Total may not match sum due to rounding

ES.2.8.2 Net Present Value of Consumer Benefits

DOE calculated net monetary savings in each year as the difference between total savings in operating costs and increases in total equipment costs in the no-new-standards case and standards cases. DOE calculated savings over the life of the products purchased in the forecast period. The NPV is the difference between the present value of operating cost savings and the present value of increased total installed costs. DOE used discount rates of 3 percent and 7 percent to discount future costs and savings to the present. DOE discounted costs and savings to 2021. The NPV results are shown in Table ES.2.16 and Table ES.2.17.

Table ES.2.16 Cumulative Net Present Value of Consumer Benefits at 3% Discount Rate in Million 2020$ for MREFs

EL	Compact Coolers (freestanding and built-in)	Coolers (freestanding and built-in)	Combination Coolers	Total*
1	787.1	8.3	11.9	807.4
2	(28.9)	(7.8)	24.9	(11.9)
3	(1,544.1)	(34.5)	(53.5)	(1,632.0)
4	(4,130.7)	(281.7)	(120.8)	(4,533.1)
5	(4,902.1)	(360.1)	(120.8)	(5,383.0)

Parentheses indicate negative (-) values.
*Total may not match sum due to rounding

Table ES.2.17 Cumulative Net Present Value of Consumer Benefits at 7% Discount Rate in Million 2020$ for MREFs

EL	Compact Coolers (freestanding and built-in)	Coolers (freestanding and built-in)	Combination Coolers	Total*
1	296.7	1.7	4.6	303.0
2	(143.1)	(10.4)	9.4	(144.1)
3	(956.7)	(28.6)	(28.9)	(1,014.2)
4	(2,216.8)	(149.5)	(61.6)	(2,427.9)
5	(2,592.1)	(189.3)	(61.6)	(2,843.0)

Parentheses indicate negative (-) values.
*Total may not match sum due to rounding

ES.2.9 Preliminary Manufacturer Impact Analysis

The purpose of the manufacturer impact analysis ("MIA") is to identify and quantify the impacts of any new or amended energy conservation standards on manufacturers. The MIA will have both quantitative and qualitative aspects, and it will include the analyses of projected industry cash flows, the industry net present value, conversion costs, and direct employment. Additionally, the MIA will seek to describe how new or amended energy conservation standards might affect manufacturing capacity and competition, as well as how standards contribute to overall regulatory burden. Finally, the MIA will seek to identify any disproportionate impacts on manufacturer subgroups, including small business manufacturers. In analyzing manufacturer impacts, the Department will do so with substantial input from manufacturers and other interested parties.

As part of the preliminary MIA, DOE develops a comprehensive manufacturer list, performs a market assessment, and evaluates consolidation trends, as presented in preliminary market and technology assessment. Characterizations of the current product offerings and market efficiency distributions are presented in the preliminary engineering analysis and shipment analysis. Preliminary investigation results related to initial financial parameters, industry-average manufacturer markups, potential sub-groups for analysis, and potential cumulative regulatory burden can be found in chapter 12 of the preliminary TSD.

ES.2.10 Other Analyses

The remaining chapters of this preliminary TSD address the following analyses, which will be performed for any NOPR issued for MREFs:

- The consumer subgroup analysis evaluates the effects of energy conservation standards on various consumer subgroups (chapter 11).
- The emissions impact analysis examines the effects of energy conservation standards on various airborne emissions (chapter 13).

- The monetization of emissions reduction benefits analysis estimates the economic impacts of reduced emissions as a result of energy conservation standards (chapter 14).
- The utility impact analysis examines impacts of energy conservation standards on the generation capacity of electric utilities (chapter 15).
- The employment impact analysis examines the indirect effects of energy conservation standards on national employment (chapter 16).
- The regulatory impact analysis examines the national impacts of non-regulatory alternatives to mandatory energy conservation standards (chapter 17).

ES.3 ISSUES ON WHICH DOE SEEKS PUBLIC COMMENT

DOE is interested in receiving comment on all aspects of this preliminary analysis. DOE especially invites comment or data to improve DOE's analyses, including information that will respond to the following questions and concerns raised in the development of this preliminary TSD.

ES.3.1 Product Classes

DOE has conducted this analysis on the existing MREF product classes, but welcomes comments on whether the number of product classes may potentially be reduced by eliminating separate icemaking product classes (C-9I and C-9I-BI). DOE requests comment on whether any additional product classes are necessary for MREFs. DOE is specifically seeking information regarding the design, operation, and energy use of MREFs that are intended to grow produce (such as microgreens or vegetables), as well as any information that would help determine whether additional product classes for these products are justified. DOE also requests information on the expected market for such products, including shipments, typical consumers, and any similar products currently available. See chapter 3 of the preliminary TSD.

ES.3.2 Design Options

DOE requests comments on the technology options and design options it is considering for MREFs. See chapter 5 of the preliminary TSD.

ES.3.3 Efficiency Levels

DOE requests comment on the efficiency levels considered in this analysis. Specifically, DOE seeks feedback on whether the efficiency levels beyond the baseline are appropriate, including the maximum technology efficiency level. See chapter 5 of the preliminary TSD.

ES.3.4 Manufacturer Production Costs

DOE requests comment on the cost-efficiency curves developed in this analysis. DOE seeks information on whether the approach and manufacturer production costs assigned to the considered design options are appropriate for MREFs. See chapter 5 of the preliminary TSD.

ES.3.5 Distribution Channels

DOE requests information on the existence of any distribution channels other than the distribution channels identified in this preliminary analysis. Also, DOE requests data on the fraction of MREF sales that go through each of the identified distribution channels, as well as the fraction of sales that go through any other identified channels (e.g., online sales channel). See chapter 6 of the preliminary TSD.

ES.3.6 Consumer Sample

DOE utilized historical data from TraQline's[f] wine chiller survey in order to develop a sample of MREF consumers for the LCC and PBP analysis. DOE requests comment and data on this approach as well as data on the distribution of MREFs by sector and geographic region. See chapter 8 of the preliminary TSD.

ES.3.7 Adjusted Volume Distributions

DOE developed distributions of adjusted volume for product classes with more than one representative unit, based on the capacity distributions reported in the TraQline wine chiller survey. DOE requests comment on this approach as well as data to further inform distributions by adjusted volume that may be used by DOE in examining potential standards for these products. See chapter 8 of the preliminary TSD.

ES.3.8 Market Efficiency Distributions

DOE developed market share distributions by efficiency level for each product class and representative unit for the no-new-standards case in the compliance year. These market share distributions are based on current model count data from DOE's CCMS Database. DOE requests comment on this approach as well as data to further inform these distributions that may be used by DOE in examining potential standards for these products. See chapter 8 of the preliminary TSD.

ES.3.9 Efficiency Distribution Trend

In the absence of data, DOE assumed that the current efficiency distribution would remain fixed over the course of the analysis period. DOE requests comment on this assumption and data to inform an efficiency trend by product class. See chapter 8 of the preliminary TSD.

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[f] TraQline is a market research company that specializes in tracking consumer purchasing behavior across a wide range of products using quarterly online surveys. www.traqline.com

ES.3.10 Installation, Maintenance and Repair Costs

DOE is not aware of any data suggesting that installation cost, maintenance cost, or repair cost changes as a function of efficiency for MREFs. DOE therefore assumed that such costs do not impact the LCC and PBP analyses. DOE requests comment and data on this assumption. See chapter 8 of the preliminary TSD.

ES.3.11 MREF Lifetimes

DOE requests comment on the MREF lifetime assumptions and methodology used in the LCC and PBP analyses. See chapter 8 of the preliminary TSD.

ES.3.12 LCC and PBP Methodologies

DOE requests comment on the overall methodology and results of the LCC and PBP analyses. See chapter 8 of the preliminary TSD.

ES.3.13 Market Share by Capacity and Product Class

DOE assumed that market shares by capacity and product class would remain fixed throughout the analysis period. However, DOE recognizes that consumers may choose amongst product classes that offer similar utility. DOE requests shipments data disaggregated by capacity and product class and that could be used to inform how consumers choose units that offer similar utility. Additionally, DOE requests data and information on any trends in the MREF market that could be used to forecast expected trends in product class market share. See chapter 8 of the preliminary TSD.

ES.3.14 Shipments Information

DOE is requesting comment and data on its shipments estimates for MREFs, as well as historical shipments data for MREFs disaggregated by product class, capacity, and efficiency level

ES.3.15 Shipments Saturation Rates and Methodology

DOE assumed the same, fixed product saturation rates as developed in the October 2016 Direct Final Rule and assumed that MREF shipments would increase in line with the increase of housing stock in the U.S. DOE requests comment and data on the MREF saturation rates and whether those should be fixed over time, as well as the overall shipments methodology for MREFs. See chapter 9 of the preliminary TSD.

ES.3.16 Consumer Subgroup Analysis

DOE welcomes input regarding which, if any, consumer subgroups should be considered when developing potential energy conservation standards for MREFs. See chapter 11 of the preliminary TSD.

ES.3.17 Emissions Analysis

DOE requests comment on its approach to conducting the emissions analysis for MREFs. See chapter 13 of the preliminary TSD.

ES.3.18 Monetization of Emissions Reductions Benefits

DOE invites input on the proposed approach for estimating monetary benefits associated with emissions reductions. See chapter 14 of the preliminary TSD.

ES.3.19 Utility Impact Analysis

DOE seeks comment on the planned approach to conduct the utility impact analysis. See chapter 15 of the preliminary TSD.

ES.3.20 Employment Impact Analysis

DOE welcomes input on its proposed approach for assessing national employment impacts. See chapter 16 of the preliminary TSD.

ES.3.21 Regulatory Impact Analysis

DOE requests any available data or reports that would contribute to the analysis of alternatives to standards for MREFs. In particular, DOE seeks information on the effectiveness of existing or past efficiency improvement programs for these products. See chapter 17 of the preliminary TSD.

ES.3.22 Manufacturer Markups

DOE requests comment on the use of a 1.25 manufacturer markup for the freestanding compact coolers and a 1.41 manufacturer markup for all other MREF product classes in the preliminary analysis. See chapter 12 of the preliminary TSD.

ES.3.23 Manufacturer Subgroups

DOE seeks comment on any other potential manufacturer subgroups, besides small business manufacturers, that could be disproportionally affected by amended energy conservation standards for MREFs. See chapter 12 of the preliminary TSD.

ES.3.24 Other Energy Conservation Standards Topics

In the field of economics, a market failure is a situation in which the market outcome does not maximize societal welfare. Such an outcome would result in unrealized potential welfare. DOE welcomes comment on any aspect of market failures, especially those in the context of amended energy conservation standards for MREFs.

In addition to the issues identified earlier in this executive summary, DOE welcomes comment on any other aspect of energy conservation standards for MREFs.

CHAPTER 1. INTRODUCTION

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CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This technical support document ("TSD") is a stand-alone report that provides the technical analyses and results supporting the information presented in the preliminary notice of public meeting and executive summary for miscellaneous refrigeration products ("MREFs").

1.2 OVERVIEW OF STANDARDS FOR MISCELLANEOUS REFRIGERATION PRODUCTS

The Energy Policy and Conservation Act, as amended ("EPCA"),[a] authorizes DOE to regulate the energy efficiency of a number of consumer products and certain industrial equipment. (42 U.S.C. 6291-6317) Title III, Part B[b] of EPCA established the Energy Conservation Program for Consumer Products Other Than Automobiles, which, in addition to identifying particular consumer products and consumer equipment as covered under the statute, permits the Secretary of Energy to classify additional types of consumer products as covered products. (42 U.S.C. 6292(a)(20)) DOE added MREFs as covered products through a final determination of coverage published in the *Federal Register* on July 18, 2016. 81 FR 46768. MREFs are consumer refrigeration products other than consumer refrigerators, refrigerator-freezers, or freezers. 10 CFR 430.2. MREFs include refrigeration products such as coolers (*e.g.*, wine chillers and other specialty products) and combination cooler refrigeration products (*e.g.*, wine chillers and other specialty compartments combined with a refrigerator, refrigerator-freezer, or freezer).

On October 28, 2016, DOE published a direct final rule (the "October 2016 Direct Final Rule") in which it adopted energy conservation standards for MREFs consistent with the recommendations from a negotiated rulemaking working group established under the Appliance Standards and Rulemaking Federal Advisory Committee. 81 FR 75194. Concurrent with the October 2016 Direct Final Rule, DOE published a NOPR in which it proposed and requested comments on the standards set forth in the direct final rule. 81 FR 74950. On May 26, 2017, DOE published a notice in the Federal Register in which it determined that the comments received in response to the October 2016 Direct Final Rule did not provide a reasonable basis for withdrawing the rule and, therefore, confirmed the adoption of the energy conservation standards established in that direct final rule. 82 FR 24214.

These current standards for MREFs are set forth in DOE's regulations at 10 CFR 430.32(aa)(1)-(2).

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[a] All references to EPCA in this document refer to the statute as amended through the Energy Act of 2020, Public Law 116–260 (Dec. 27, 2020).
[b] For editorial reasons, upon codification in the U.S. Code, Part B was re-designated Part A.

1.3 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

Under EPCA, when DOE is studying new or amended standards, it must consider, to the greatest extent practicable, the following seven factors (42 U.S.C. 6295(o)(2)(B)(i)):

(1) The economic impact of the standard on the manufacturers and consumers of the products subject to the standard;

(2) The savings in operating costs throughout the estimated average life of the covered products in the type (or class) compared to any increase in the price, initial charges, or maintenance expenses for the covered products that are likely to result from the standard;

(3) The total projected amount of energy (or as applicable, water) savings likely to result directly from the standard;

(4) Any lessening of the utility or the performance of the products likely to result from the standard;

(5) The impact of any lessening of competition, as determined in writing by the Attorney General, that is likely to result from the standard;

(6) The need for national energy and water conservation; and

(7) Other factors the Secretary of Energy (Secretary) considers relevant.

Other statutory requirements are set forth in 42 U.S.C. 6295(o)(1)-(2)(A), (2)(B)(ii)-(iii), and (3)-(4).

DOE considers stakeholder participation to be a very important part of the process for setting energy conservation standards. Through formal public notifications (*i.e.*, *Federal Register* notices), DOE actively encourages the participation and interaction of all stakeholders during the comment period in each stage of a rulemaking. Beginning with the framework document and during subsequent comment periods, interactions among stakeholders provide a balanced discussion of the information that is required for a potential standards rulemaking.

Before DOE determines whether to adopt a proposed energy conservation standard, it must first solicit comments on the proposed standard. (42 U.S.C. 6295(m)(2)(B)) Any new or amended standard must be designed to achieve significant additional conservation of energy and be technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) To determine whether economic justification exists, DOE must review comments on the proposal and determine that the benefits of the proposed standard exceed its burdens to the greatest extent practicable, weighing the seven factors listed above. (42 U.S.C. 6295(o)(2)(B)(i))

On December 8, 2020, DOE published notice that it was initiating an early assessment review to determine whether any new or amended standards would satisfy the relevant requirements of EPCA for a new or amended energy conservation standard for MREFs and a request for information ("RFI"). 85 FR 78964 ("December 2020 Early Assessment RFI").[c]

Comments received to date as part of the current process have helped DOE identify and resolve issues related to the preliminary analyses. Chapter 2 of this TSD summarizes the comments received and includes DOE's responses.

DOE developed spreadsheets for the life-cycle cost ("LCC"), payback period ("PBP"), and national impact analyses for MREFs. DOE developed an LCC spreadsheet that calculates the LCC and PBP at various energy efficiency levels. DOE also developed a national impact analysis spreadsheet that calculates the national energy savings ("NES") and national net present values ("NPVs") at various energy efficiency levels. This spreadsheet includes a model that forecasts the impacts of potential amended energy conservation standards at various levels on product shipments. All of these spreadsheets are available on the DOE website for MREFs at: *www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=39&action=viewlive*.

1.4 STRUCTURE OF THE DOCUMENT

This TSD outlines the analytical approaches used in the preliminary analysis. The TSD consists of 17 chapters and supporting appendices.

Chapter 1	Introduction: provides an overview of the appliance standards program and how it applies to this preliminary analysis, describes the purpose of the TSD, and outlines the structure of the document.
Chapter 2	Analytical Framework, Comments from Interested Parties, and DOE Responses: describes the general rulemaking process and issues for the preliminary analysis.
Chapter 3	Market and Technology Assessment: characterizes the MREF market and the technologies available for increasing efficiency.
Chapter 4	Screening Analysis: determines which technology options are viable for consideration in the engineering analysis.
Chapter 5	Engineering Analysis: discusses the methods used for developing the relationship between increased manufacturing cost and increased efficiency.

[c] Available at www.regulations.gov/docket/EERE-2020-BT-STD-0039.

Chapter 6	Markups Analysis: describes the methods used for establishing markups for converting manufacturing cost to customer purchase price and presents results of the preliminary analysis.
Chapter 7	Energy Use Analysis: describes the sources and methods used for generating energy use estimates for the considered MREFs as a function of potential standard levels and presents results of the preliminary analysis.
Chapter 8	Life-Cycle Cost and Payback Period Analyses: describes the methods used for analyzing the economic effects of new or amended efficiency standards on individual consumers and users of the products with respect to LCC savings and PBP of higher efficiency products and presents results of the preliminary analysis.
Chapter 9	Shipments Analysis: describes the methods used for forecasting shipments with and without amended energy efficiency standards and presents results of the preliminary analysis.
Chapter 10	National Impact Analysis: describes the methods used for estimating the impacts of potential standards on national energy consumption and national economic benefit to consumers and presents the preliminary results of the analysis.
Chapter 11	Consumer Subgroup Analysis: describes the methods to be used for analyzing the effects of potential standards on a subgroup of consumers compared to all consumers.
Chapter 12	Preliminary Manufacturer Impact Analysis: discusses the effects of energy conservation standards on the finances and profitability of MREF manufacturers.
Chapter 13	Emissions Analysis: describes the methods to be used to analyze the impact of potential standards on sulfur dioxide, nitrogen oxides, and mercury, as well as on carbon dioxide and other greenhouse gas emissions.
Chapter 14	Monetization of Emission Reductions Benefits: describes the methods to be used for estimating the monetary benefits likely to result from reduced emissions expected to result from potential standards.
Chapter 15	Utility Impact Analysis: describes the methods to be used for analyzing key impacts of potential standards on electric utilities.
Chapter 16	Employment Impact Analysis: describes the methods to be used for analyzing the impact of potential standards on national employment.

Chapter 17	Regulatory Impact Analysis: describes the methods to be used for analyzing the impact of non-regulatory alternatives to energy conservation standards compared to standards.
Appendix 3A	Current Market Energy Efficiency by Product Class
Appendix 6A	Incremental Markups
Appendix 8A	User Instructions for the Life-Cycle Cost Analysis Spreadsheet
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CHAPTER 2. ANALYTICAL FRAMEWORK, COMMENTS FROM INTERESTED PARTIES, AND DOE RESPONSES

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CHAPTER 2. ANALYTICAL FRAMEWORK, COMMENTS FROM INTERESTED PARTIES, AND DOE RESPONSES

2.1 INTRODUCTION

The Energy Policy and Conservation Act, as amended ("EPCA")[1] (42 U.S.C. 6291-6317), requires that energy conservation standards established by the U.S. Department of Energy ("DOE") be designed to achieve the maximum improvement in energy efficiency (or in the case of certain covered products water efficiency) that is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) This chapter provides a description of the general analytical framework that DOE uses in developing such standards, and in particular, energy conservation standards for miscellaneous refrigeration products ("MREFs"). It includes a description of the methodology, the analytical tools, and relationships among the various analyses. This chapter also provides an overview of the preliminary activities DOE has conducted and information DOE has received from stakeholder comments. Finally, this chapter provides cross-references to the other chapters of this technical support document ("TSD") that address DOE's analytical approach, inputs, and findings.

The analyses performed as part of the preliminary analysis stage and presented in this TSD are listed below.

- A market and technology assessment to characterize the MREF market, identify existing technology options, and outline product classes.

- A screening analysis to review each technology option and determine if it is technologically feasible; is practicable to manufacture, install, and service; would adversely impact product utility or availability; would have adverse impacts on health and safety; or would utilize proprietary technology that represents a unique pathway to achieving a given efficiency level.

- An engineering analysis to develop cost-efficiency relationships that show the manufacturer's cost of achieving increased efficiency.

- A markups analysis to develop distribution channel markups that relate the manufacturer selling price ("MSP") to the retail price paid by the consumer.

- An energy use analysis to determine energy use estimates for MREFs for a representative set of users.

- A life-cycle cost ("LCC") analysis that calculates, at the consumer level, the discounted savings in operating costs throughout the estimated average life of the

[1] All references to EPCA in this document refer to the statute as amended through the Energy Act of 2020, Public Law 116-260 (Dec. 27, 2020).

MREF, compared to any increase in the installed costs likely to result directly from imposition of amended energy conservation standards.

- A payback period ("PBP") analysis to estimate the amount of time it takes consumers to recover the higher purchase expense of more efficient MREFs through lower operating costs likely to result directly from imposition of amended energy conservation standards.

- A shipments analysis that estimates shipments of MREFs over the time period examined in the analysis.

- A national impact analysis ("NIA") that assesses the aggregate impacts, at the national level, of potential amended energy conservation standards as measured by the net present value ("NPV") of total consumer economic impacts and national energy savings ("NES").

- A preliminary manufacturer impact analysis ("MIA") that begins to evaluate the impacts of amended energy conservation standards on manufacturers, such as impacts on capital conversion expenditures, marketing costs, shipments, and research and development costs.

The analyses DOE will perform in any subsequent notice of proposed rulemaking ("NOPR") stage include those listed below. In addition, DOE will revise the analyses it performed in the preliminary analysis stage based on comments and new information received on topics including, but not limited, to those listed below.

- An LCC subgroup analysis to evaluate variations in customer characteristics that might cause amended energy conservation standards to disproportionately impact particular consumer sub-populations, such as low-income households.

- An MIA to estimate the financial impact of amended energy conservation standards on manufacturers and to calculate impacts on competition, manufacturing employment, and manufacturing capacity.

- A utility impact analysis that estimates the effects of proposed standards on the installed capacity and the generating base of electric utilities;

- An employment impact analysis to assess the aggregate impacts on national employment.

- An emissions analysis to assess the impacts of amended energy conservation standards on the environment.

- An emissions monetization analysis to assess the benefits associated with emissions reductions.

- A regulatory impact analysis ("RIA") to examine major alternatives to amended energy conservation standards that potentially could achieve substantially the same regulatory goal at a lower cost.

On December 8, 2020, DOE published an early assessment review and request for information ("RFI") to collect data and information to help DOE determine whether amended standards for MREFs would result in a significant amount of additional energy savings and whether those standards would be technologically feasible and economically justified. 85 FR 78964 ("December 2020 EA RFI").

In the remainder of this chapter, DOE summarizes the key comments received from interested parties in response to the December 2020 EA RFI and describes DOE's responses to those comments. The issues for which DOE seeks public comment are listed in the executive summary of this TSD and are discussed in further detail in the following chapters of this TSD; however, DOE is interested in receiving comment on all aspects of this preliminary analysis.

DOE received 7 comments in response to the December 2020 EA RFI from the interested parties listed in Table 2.1.

Table 2.1 December 2020 EA RFI Commenters

Organization(s)	**Reference in this TSD**	**Organization Type**
Appliance Standards Awareness Project	ASAP	Efficiency Organization
Association of Home Appliance Manufacturers	AHAM	Trade Association
GE Appliances, a Haier Company	GEA	Manufacturer
Legacy Companies	Legacy Companies	Manufacturer
Northwest Energy Efficiency Alliance	NEEA	Efficiency Organization
Pacific Gas and Electric, Southern California Edison, San Diego Gas and Electric	CA IOUs	Utility Association
Sub Zero Group, Inc.	Sub Zero	Manufacturer

A parenthetical reference provides a reference for information located in the docket of DOE's rulemaking to develop energy conservation standards for MREFs. (Docket No. EERE-2017-BT-STD-0003, which is maintained at www.regulations.gov/#!docketDetail;D=EERE-2020-BT-STD-0036). The references are arranged as follows: (commenter name, comment docket ID number, page of that document).

2.2 TEST PROCEDURE AND ENERGY USE METRICS

Currently, manufacturers are required to demonstrate compliance with the energy conservation standards for MREFs found at section 430.32(aa) of Title 10 of the Code of Federal Regulations ("CFR"). Manufacturers determine compliance based on testing according to the currently applicable DOE test procedure for these products at 10 CFR part 430, subpart B, appendix A ("Appendix A").

Appendix A provides the requirements for measuring and calculating the annual energy use in kilowatt-hours per year ("kWh/year") and adjusted volume in cubic feet ("ft^3"). The current energy conservation standards are equations that calculate the maximum allowable annual energy use based on a model's total adjusted volume.

In response to the December 2020 EA RFI, DOE received several comments regarding test procedure issues that did not directly affect this preliminary analysis. These comments referred to the representativeness of a closed-door test conducted at a single elevated ambient temperature condition. DOE considered comments regarding the test procedure as part of the most recent test procedure rulemaking.

On October 12, 2021, DOE published in the *Federal Register* a final rule amending the test procedures for MREFs and other consumer refrigeration products (the "October 2021 Test Procedure Final Rule"). 86 FR 56790 (October 12, 2021). The October 2021 Test Procedure Final Rule incorporates by reference the most recent industry test procedure, AHAM Standard HRF-1, "Energy and Internal Volume of Consumer Refrigeration Products" ("AHAM HRF-1-2019").[2] DOE determined that the test procedure amendments are not expected to impact the measured energy use of consumer refrigeration products, including MREFs, as compared to the test procedure in place at the time of the October 2021 Test Procedure Final Rule. 86 FR 56790.

2.3 MARKET AND TECHNOLOGY ASSESSMENT

The market and technology assessment characterizes the relevant product markets and existing technology options, including working prototype designs, for the considered products.

2.3.1 Market Assessment

When analyzing potential energy conservation standards, DOE initially develops information that provides an overall picture of the market for the products analyzed, including the nature of the products, the industry structure, and market characteristics for the products. This activity consists of both quantitative and qualitative efforts based primarily on publicly available information. In the context of the present analysis, the subjects addressed in the market assessment for MREFs include manufacturers, trade associations, and the quantities and types of products sold and offered for sale. DOE examined both large and small, foreign, and domestic manufacturers. Finally, DOE reviewed other energy efficiency programs from utilities, individual States, and other organizations.

DOE reviewed available public literature and information provided in comments from interested parties to develop an overall understanding of the MREF industry in the United States.

[2] Available for purchase at www.aham.org/ItemDetail?iProductCode=20009&Category=MADSTD.

A full discussion of DOE's market assessment is provided in chapter 3 of this TSD, which describes the market analysis and resulting information.

2.3.1.1 Product Definitions and Scope

DOE's definitions for MREFs are included at 10 CFR 430.2. MREFs are consumer refrigeration products other than refrigerators, refrigerator-freezers, or freezers, which include coolers and combination cooler refrigeration products. 10 CFR 430.2. MREFs include refrigeration products such as coolers (*e.g.*, wine chillers and other specialty products) and combination cooler refrigeration products (*e.g.*, wine chillers and other specialty compartments combined with a refrigerator, freezer, or refrigerator-freezer). DOE did not receive any comments from stakeholders in response to the December 2020 EA RFI regarding its existing product definitions for MREFs.

In response to the December 2020 EA RFI, DOE received comments regarding energy conservation standards for icemakers and commercial refrigeration equipment. Legacy Companies expressed concern regarding the potential impacts of reduced energy consumption on food safety for commercial refrigeration equipment and commented as to the need for rapid temperature pull-down capabilities in this equipment. (Legacy Companies, No. 2, p. 1) Commercial refrigerators, freezers, and refrigerator-freezers are by definition not consumer products (see 10 CFR 431.61) and are therefore outside the scope of this analysis for MREFs.

ASAP and the CA IOUs recommended that DOE consider establishing standards for small icemakers (with harvest rates less than 50 lb/day). (ASAP, No. 4, p. 2; CA IOUs, No. 5, p. 5) The CA IOUs suggested that DOE collect technical and market data on all small icemakers (portable, undercabinet, and free-standing icemakers) in order to determine the potential savings of adopting energy conservation standards of these previously considered products due to the possibility that these products have experienced significant market growth. (CA IOUs, No. 5, p. 5) NEEA provided similar comments and additional data indicating the potential for energy savings with standards for icemakers with harvest rates less than 50 lb/day. (NEEA, No. 7, pp. 7-9)

In a final coverage determination establishing the scope of energy conservation standards for MREFs, DOE stated that consumer icemakers are significantly different from the other product categories considered for coverage under MREFs, and, therefore, excluded them from MREF coverage. 81 FR 46768, 46773 (July 18, 2016). DOE will consider, to the extent applicable, the comments regarding ice makers with harvest rates under 50 lb/day in its ongoing assessment of whether new or amended energy conservation standards for automatic commercial ice makers are appropriate.[3]

[3] On September 29, 2020, DOE published an early assessment RFI for energy conservation standards for commercial automatic icemakers. 85 FR 60923. See also, Docket No. EERE-2017-BT-STD-0022, which is maintained at https://www.regulations.gov.

2.3.1.2 Product Classes

DOE's existing standards for MREFs are based on 12 product classes for coolers and combination cooler refrigeration products. These product classes currently separate freestanding products from built-in products, compact products from full-size products, and combination refrigeration products of various compartment configurations.

DOE received several comments in response to the December 2020 EA RFI regarding considerations for built-in product classes. Sub Zero recommended that DOE continue to consider the unique characteristics of built-in products. (Sub Zero, No. 8, p. 1) Other comments discussed technology options and energy consumption considerations for built-in products, which are discussed in section 2.5.1 of this chapter.

While only certain product classes were directly analyzed, DOE accounted for the 12 existing product classes for MREFs in this preliminary analysis, including built-in product classes.

DOE is also aware that there are new products entering the market which are designed to grow produce (such as microgreens or vegetables) indoors. Some of these products utilize refrigeration systems to maintain internal compartment temperatures. See, e.g., 86 FR 35766 (July 7, 2021) (discussing operation of GEA's In-Home Grower product). While DOE has not yet analyzed these novel products in this preliminary analysis, DOE may consider whether separate consideration for these units is justified at a subsequent NOPR stage, should sufficient information about the operation and energy use of these products become available. DOE requests information on these products, including whether and how to differentiate them from other MREFs, typical consumer use data, unit operation and construction, and on any potential for efficiency improvements. A more detailed discussion of such products is provided in chapter 3 of this TSD.

2.3.2 Technology Assessment

DOE typically uses information relating to existing and past technology options and working prototype designs as inputs to determine what technologies manufacturers may use to attain higher performance levels. In consultation with interested parties, DOE develops a list of technologies for consideration. Initially, these technologies encompass all those shown to be technologically feasible.

DOE developed a list of technologies for MREFs from previous rulemaking information, trade publications, technical papers, manufacturer literature, component manufacturer literature, and comments from interested parties. Because existing products contain many technologies for improving product efficiency, product literature and direct examination during product testing and reverse engineering provided additional information.

NEEA commented that the following technologies may be used to improve efficiency: Gas-filled insulation panels partitioned with aluminum foil; alternative strategies to electric resistance anti-sweat heaters; thermostat temperature controls; addition of circulation fans or modified air duct design in place of natural convection; airfoil shaped fan blades and airflow straighteners; electrically commutated (brushless direct current) motors for fans and compressors; natural refrigerants; lowering pressure drop in refrigerant piping; alternative non-vapor compression methods of refrigeration. (NEEA, No. 7, pp. 2-4) Additionally, NEEA indicated that variable-speed compressors result in energy savings in field use. (NEEA, No. 7, p. 6)

Chapter 3 of this TSD includes the detailed list of all technology options identified for MREFs, including those identified by NEEA. Comments received from interested parties regarding the efficiency impacts of certain technology options are discussed in section 2.5.1 of this chapter. DOE continues to request data and information on the range of technology options considered in this analysis, including feedback on whether the range of efficiencies and assumptions incorporated in the analysis are appropriate for MREFs.

2.4 SCREENING ANALYSIS

The screening analysis examines various technologies as to whether they: (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on product utility or availability; (4) have adverse impacts on health and safety; or (5) would utilize proprietary technology that represents a unique pathway to achieving a given efficiency level. 10 CFR part 430, subpart C, appendix A, 6(c)(3) and 7(b). DOE developed an initial list of technology options as identified in the technology assessment. Then DOE reviewed the list to assess each technology option against the screening criteria with input from interested parties.

In response to the December 2020 EA RFI, AHAM indicated that solid doors would result in improved efficiency but at the significant cost of consumer utility. AHAM specified that the glass door is a major feature for MREFs, and a major motivation for consumers in purchasing MREFs is the ability to see the contents of their coolers. (AHAM, No. 3, p. 3)

DOE screened out solid doors from further consideration in this preliminary analysis under screening criterion #3 based on initial consideration of the use of that feature by consumers, as described by AHAM.

NEEA and Sub Zero provided comments about certain aspects of MREF design that might restrict the use of certain components. (NEEA, No. 7, p. 4; Sub Zero, No. 8, pp. 1-2) Sub Zero commented that built-in MREFs have limitations because these designs may have restricted condenser airflow, longer door gasket length per unit of storage volume, limits to insulation thickness, and complicated door hinging that increases cabinet heat load. (Sub Zero, No. 8, pp. 1-2) NEEA encouraged DOE to consider volume constraints for MREFs in general, suggesting that MREF products tend to have less space in the cabinet compared to larger refrigerators. NEEA also noted that it is possible to shrink one component of a refrigeration system and/or allow for an increase in the volume of a larger component, and that DOE should consider these volume trade-offs. (NEEA, No. 7, p. 4)

In conjunction with its own evaluation, DOE has considered the NEEA and Sub Zero assessments of technology options in the current market. DOE has screened out several technology options, which are discussed in detail in Chapter 4 of this TSD. At this time, DOE is not screening out the technology options identified by NEEA and Sub Zero as none of the five screening criteria appears applicable. Chapter 4 of this TSD provides further detailed discussion of the results of the screening analysis. In the engineering analysis, discussed in detail in chapter 5 of this TSD, DOE further considered those technologies that it did not screen out in the screening analysis. Technology options that were not screened out on the basis of the five screening criteria but are not expected to result in practical improvements in efficiency for MREFs (or that may negatively impact consumer utility as implemented in certain product configurations) were not included as design options in the engineering analysis.

Chapter 4 of this TSD provides further detailed discussion of the results of the screening analysis. In the engineering analysis, discussed in detail in chapter 5 of this TSD, DOE further considered those technologies that it did not screen out in the screening analysis.

2.5 ENGINEERING ANALYSIS

The purpose of the engineering analysis (chapter 5 of this TSD) is to establish the relationship between the efficiency and cost of MREFs. There are two elements to consider in the engineering analysis; the selection of efficiency levels to analyze (i.e., the "efficiency analysis") and the determination of product cost at each efficiency level (i.e., the "cost analysis"). In determining the performance of higher-efficiency products/equipment, DOE considers technologies and design option combinations not eliminated by the screening analysis. For each product class, DOE estimates the baseline cost, as well as the incremental cost for the product at efficiency levels above the baseline. The output of the engineering analysis is a set of cost-efficiency "curves" that are used in downstream analyses (i.e., the LCC and PBP analyses and the NIA).

In this preliminary analysis, DOE has analyzed a sub-set of product classes and applied the analysis to other product classes, as has been done for previous rulemakings. For instance, DOE directly analyzed the freestanding cooler product classes and applied the results to the built-in product classes. Similarly, DOE relied on the recent analysis developed for consumer refrigerators, refrigerator-freezers, and freezers to evaluate potential efficiency improvements for combination cooler refrigeration products.[4]

DOE received comments from Sub Zero and ASAP regarding considerations for built-in product classes. Sub Zero commented that built-ins use more energy than freestanding units due to inherent design differences, and the overall difference in efficiency is between 5% and 15% depending on model and configuration. Sub Zero noted that DOE established separate product classes for built-in MREFs to account for unique consumer utility that built-in designs provide.

[4] A technical support document for the preliminary analysis to consider amendments to the energy conservation standards for refrigerators, refrigerator-freezers, and freezers was published on October 15, 2021 and is available online at www.regulations.gov/docket/EERE-2017-BT-STD-0003/document.

Sub Zero stated that credits for built-ins are currently included in the standards for refrigerators and combination-cooler MREFs, but in the interest of achieving a successful outcome in the initial ASRAC negotiations,[5] the industry did not request a credit for built-in coolers; however, Sub Zero stated that it was understood that built-in coolers would need credits in any subsequent round of standards and therefore separate built-in product classes were recommended by ASRAC to permit different future standards levels for free-standing and built-in coolers. (Sub Zero, No. 8, pp. 1-2)

ASAP commented that there are both freestanding and built-in coolers across the range of volumes that consume significantly less energy than minimally compliant models, and the most efficient product is a built-in cooler, which consumes 54% less energy than the standard. (ASAP, No. 4, p. 1)

DOE performed an assessment of the range of efficiencies available for built-in cooler product classes to compare these classes to the corresponding freestanding product classes. Based on current market availability, both built-in and the corresponding freestanding product classes appear to have similar potential for efficiency improvement relative to the current energy conservation standard. Additionally, while certain freestanding products may not have the same design restrictions as built-in coolers, DOE observed that many freestanding coolers available on the market are designed for optional built-in installation, and therefore have similar designs (*e.g.*, the same outer dimensions and airflow pathways). While DOE analyzed only freestanding product classes for this preliminary engineering analysis, DOE relied on freestanding models with optional built-in installation as the basis of this analysis and expects that the resulting efficiency levels, design options, and costs are also applicable to the corresponding built-in product classes. The details of this analysis are presented in chapter 5 of this TSD.

Hence, DOE did not directly analyze built-in product classes for this preliminary engineering analysis, but DOE continues to seek information on this topic.

Additionally, AHAM commented that, in designing MREFs, manufacturers balance cost, functional performance, and energy consumption, and the precise balance varies by model so that manufacturers select different mixes of technologies for each product platform. (AHAM, No. 3, pp. 2-3)

In this preliminary analysis, DOE directly analyzed MREFs at representative volumes and efficiency levels based on a review of the market. Chapter 5 of this TSD discusses the product classes DOE analyzed, the representative baseline units, the incremental efficiency levels, the methodology DOE used to develop the manufacturer production costs ("MPCs"), and the resulting cost-efficiency curves.

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[5] In its previous rulemaking, DOE established an Appliance Standards and Rulemaking Federal Advisory Committee ("ASRAC") that would use the negotiated rulemaking process to discuss and reach consensus recommendations on the scope of coverage, definitions, test procedures, and energy conservation standards for MREFs. *See* 81 FR 46768, 46770 (July 18, 2016).

2.5.1 Efficiency Analysis

DOE typically uses one of two approaches to develop energy efficiency levels for the engineering analysis: (1) relying on observed efficiency levels in the market (*i.e.*, the efficiency-level approach), or (2) determining the incremental efficiency improvements associated with incorporating specific design options to a baseline model (*i.e.*, the design-option approach). Using the efficiency-level approach, the efficiency levels established for the analysis are determined based on the market distribution of existing products (in other words, based on the range of efficiencies and efficiency level "clusters" that already exist on the market). Using the design option approach, the efficiency levels established for the analysis are determined through detailed engineering calculations and/or computer simulations of the efficiency improvements from implementing specific design options that have been identified in the technology assessment. DOE may also rely on a combination of these two approaches. For example, the efficiency-level approach (based on actual products on the market) may be extended using the design option approach to interpolate to define "gap fill" levels (to bridge large gaps between other identified efficiency levels) and/or to extrapolate to the max-tech level (particularly in cases where the max-tech level exceeds the maximum efficiency level currently available on the market).

For this preliminary analysis, DOE used the efficiency-level approach, supplemented with the design-option approach for certain gap fill and max-tech efficiency levels. The efficiency levels that DOE considered in the engineering analysis are attainable using technologies currently available on the market for MREFs. DOE used the results of the testing and teardown analyses to determine a representative set of technologies and design strategies that manufacturers could use to achieve each higher efficiency level. Technologies not eliminated in the screening analysis and further shown to provide incremental efficiency benefits were considered as design options. For this preliminary analysis, DOE considered the current standards for MREFs established in 10 CFR 430.32(aa) as the baseline efficiency level for each product class.

DOE reviewed data in its Compliance Certification Management System ("CCMS")[6] to evaluate the range of MREF efficiencies currently available on the market. DOE used these data to identify clusters of models that correspond with higher efficiency levels specified in other programs (*e.g.,* ENERGY STAR™). This information was used as the basis for selecting models for analysis at the next efficiency level beyond the baseline considered in the preliminary analysis. Beyond the efficiency levels defined by models available on the market, DOE relied upon the design-option approach to estimate performance beyond the models directly analyzed to a hypothetical max-tech efficiency level.

In the December 2020 EA RFI, DOE sought feedback on technology options which may lead to improvements in MREF efficiencies. 85 FR 78964, 78966.

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[6] Available at www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A*.

NEEA commented that there are a number of technologies available to improve MREF efficiency and encouraged DOE to consider the nine technologies in Table IV.3 of DOE's October 2016 Direct Final Rule[7] based on an assumption that many of these technologies are employed in today's market considering the range of efficiency observed. (NEEA, No. 7, p. 2) NEEA further commented that the max-tech level considered in the analysis supporting the October 2016 Direct Final Rule is available on the market and therefore no longer represents the max-tech. NEEA encouraged DOE to consider efficiency levels beyond the max-tech considered for the October 2016 Direct Final Rule. (NEEA, No. 7, pp. 5–6)

GEA commented that no innovative technology has become available on the market since the last standards rulemaking for MREFs. (GEA, No. 6, p. 1)

AHAM commented that there is no new technology that would allow for significant per-unit reduction in energy consumption, but rather, any changes to the standard would require small improvements through modifications of components, adding insulation, changing controls, *etc*. AHAM stated that manufacturers must balance cost, functional performance, and energy consumption, and that the balance varies by model leading manufacturers to select different technology mixes by product platform. AHAM stated that as a rule, manufacturers make component changes first, and only if this is not sufficient to reach the necessary levels of efficiency do they make design changes. AHAM explained this is because the more radical or comprehensive the design change, the more likely that retooling is necessary and, thus, the greater the product cost and the investment. (AHAM, No. 3, pp. 2-3)

For this preliminary analysis, DOE has relied on current MREF market availability to define efficiency levels from baseline to maximum available and extended efficiency to a max-tech level by estimating the performance of additional design options not observed in products currently available. DOE provides a detailed discussion on technology options and design options considered at efficiency levels beyond the baseline in chapters 3 and 5 of this TSD. DOE additionally received comments regarding specific technology options, as discussed below.

ASAP asserted that alternative refrigerants represent a path to higher efficiency levels beyond the "max-tech" levels evaluated in the last rulemaking, and many coolers are now using R600A refrigerant (isobutane), as opposed to R134A. ASAP indicated that R600A may lead to efficiency improvements up to 6.5%. (ASAP, No. 4, p. 2)

DOE's review of the MREF market identified a number of models that use alternative refrigerants currently available on the market. Additionally, DOE has identified models using alternative refrigerants, specifically R600A, in all of the directly analyzed product classes, including in models at the baseline efficiency. In this preliminary analysis, each efficiency level represents a design utilizing R600A refrigerant and, therefore, DOE did not consider a refrigerant change as an incremental design option to achieve higher efficiencies.

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[7] On October 28, 2016, DOE published a Direct Final Rule (the "October 2016 Direct Final Rule") adopting energy conservation standards for MREFs. 81 FR 75194.

AHAM commented that higher-efficiency fan blades can incur costs to implement but will not lead to significant energy savings. AHAM stated that vacuum-insulated panels are also an expensive technology option to improve efficiency, but these cannot be used for all model types. (AHAM, No. 3, p. 3)

DOE has initially determined that higher-efficiency fan blades are not likely to result in significant efficiency improvements for typical MREF designs and has not considered this design option in the preliminary cost-efficiency curves. DOE did, however, consider the costs associated with implementing vacuum-insulated panels at the efficiency levels beyond those available on the market. Based on information gathered during the previous rulemaking and the recent preliminary analysis for refrigerators, refrigerator-freezers, and freezers, DOE expects this design option to be feasible for MREFs.

In the engineering analysis, DOE considers all design options that meet the screening criteria. DOE determined that certain design options that met the screening criteria were not appropriate for further consideration in the engineering analysis for three reasons: limited information available on potential energy efficiency benefits, no significant corresponding energy use reduction, or complete market adoption.

Each of these technology options and reasons for exclusion from the engineering analysis are discussed in detail in chapter 5 of this TSD.

2.5.2 Cost Analysis

The cost analysis portion of the Engineering Analysis is conducted using one or a combination of cost approaches. The selection of cost approach depends on a suite of factors, including the availability and reliability of public information, characteristics of the regulated product, availability and timeliness of purchasing the product on the market. The cost approaches are summarized as follows:

- Physical teardowns: Under this approach, DOE physically dismantles a commercially available product, component-by-component, to develop a detailed bill of materials for the product.

- Catalog teardowns: In lieu of physically deconstructing a product, DOE identifies each component using parts diagrams (available from manufacturer websites or appliance repair websites, for example) to develop the bill of materials for the product.

- Price surveys: If neither a physical nor catalog teardown is feasible (for example, for tightly integrated products such as fluorescent lamps, which are infeasible to disassemble and for which parts diagrams are unavailable) or cost-prohibitive and otherwise impractical (*e.g.*, large commercial boilers), DOE conducts price surveys using publicly available pricing data published on major online retailer websites and/or by soliciting prices from distributors and other commercial channels.

For this analysis, DOE conducted the cost analysis using a hybrid of physical and catalog teardowns. The resulting bill of materials provides the basis for the MPC estimates at each efficiency level for each analyzed product class. To account for manufacturers' non-production costs and profit margin, DOE applies a non-production cost multiplier (the manufacturer markup) to the MPC. DOE developed an average manufacturer markup by examining publicly available financial information and product-specific parameters published in the October 2016 Direct Final Rule. 81 FR 75194. The resulting manufacturer selling price ("MSP") is the price at which the manufacturer distributes a unit into commerce. See chapter 12 of this TSD for additional details on manufacturer markups.

Chapter 5 of this TSD includes information on the inputs used to determine the cost-efficiency curves. It also includes information on the various components and features incorporated into designs for higher efficiency MREFs.

In response to the December 2020 EA RFI, AHAM commented that assessing the cost effectiveness of technology options and the incremental cost to achieve lower energy use must be done within a product platform because technology options, in and of themselves, do not have cost/performance characteristics. AHAM stated that those characteristics can only be measured within a product platform, taking into account any associated changes in the internal mold configurations for the inner liner and doors, for example. (AHAM, No. 3, p. 3)

While DOE aimed to select representative units for each analyzed product class from a single manufacturer and within the same product platform, this was not always possible because not all product platforms span a wide range of efficiency levels. For the engineering analysis, DOE considers the specific per-model product costs associated with design changes. DOE considers additional manufacturer conversion cost impacts associated with product re-design and manufacturing investments as part of any subsequent manufacturer impact analysis.

2.6 MARKUPS ANALYSIS

DOE analyzed product markups to convert the MSPs to consumer prices, which are then used in the LCC and PBP analysis. To develop markups, DOE identified how the products are distributed from the manufacturer to the consumer (the distribution channels). After establishing appropriate distribution channels for each product, DOE used economic data from the U.S. Census Bureau to define how prices are marked up as the products pass from manufacturers to consumers. See chapter 6 of this TSD for details on the development of markups.

2.7 ENERGY-USE CHARACTERIZATION

The purpose of the energy use analysis is to determine the annual energy consumption of MREFs at different efficiencies in representative U.S. households, and to assess the energy savings potential of increased MREF efficiency. The energy use analysis estimates the range of energy use of MREFs in the field (*i.e.*, as they are actually used by consumers).

DOE determined a range of annual energy use of MREFs as a function of unit volume. DOE developed distributions of adjusted volume for product classes with more than one representative unit (the freestanding compact class and the corresponding built-in product class) based on the capacity distributions reported in the TraQline® wine chiller data spanning from Q1 2019 to Q2 2021.[8] DOE also developed a sample of households that use MREFs based on the TraQline wine chiller data. For each sample household, DOE randomly assigned a product volume from the volumes analyzed in the engineering analysis. For each volume and considered efficiency level, DOE derived the energy consumption as measured by the DOE test procedure in Appendix A.

2.8 LIFE-CYLE COST AND PAYBACK PERIOD ANALYSIS

The impacts of amended energy conservation standards on consumers often include a change in operating expense (usually decreased energy costs) and a change in purchase price (usually increased). The LCC of a product is the cost it incurs over its lifetime, taking into account both purchase price and operating expenses. The PBP represents the time it takes to recover the additional installed cost of the more efficient products through annual operating-cost savings. DOE analyzes the net effect on consumers by calculating the LCC and PBP using the engineering performance data, the markups analysis, and the energy use analysis. Inputs to the LCC calculation include the installed cost to the consumer (purchase price plus installation cost), operating expenses, the lifetime of the product, and a discount rate. Inputs to the PBP calculation include the installed cost to the consumer and first-year operating costs.

DOE acquired ten years of historical data from TraQline's wine chiller survey in order to develop a sample of MREF consumers for the LCC and PBP analysis. TraQline is a market research company specializing in tracking consumer purchasing behavior across a wide range of products using quarterly online surveys.[9] The survey panel is weighted against the U.S. Census data based on the survey's demographic characteristic to make the sample representative of the U.S. population. The wine chiller survey asked respondents about the product features of the wine chillers they recently purchased, as well as the purchasing channel of the products. To account for the more recent MREF consumers, DOE used the last two and half years of survey data (2019 Q1 to 2021 Q2) to construct the household sample used in this preliminary analysis.

Recognizing that several inputs to the determination of consumer LCC and PBP are either variable or uncertain, DOE conducted the LCC and PBP analyses by modeling the variability in the inputs using Monte Carlo simulation and probability distributions. Each Monte Carlo simulation consists of 10,000 LCC and PBP calculations. The model performs each calculation using input values that are either sampled from probability distributions and household samples or characterized with single point values.

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[8] TraQline® is a quarterly market share tracker of 150,000+ consumers.
[9] For more information see www.traqline.com.

DOE used a "simple" PBP for this rulemaking, which is the ratio of the increase in purchase cost (*i.e.*, from a less efficient design to a more efficient design) to the decrease in annual operating expenditures. The "simple" PBP does not take into account other changes in operating expenses over time or the time value of money.

DOE calculated the LCC and PBP for all MREF consumers as if each were to purchase a new product in the expected year of required compliance with new or amended standards. The analysis applied a compliance date for any amended standards to MREFs manufactured five years after the date on which any new or amended standard is published. (See 42 U.S.C. 6295(l)(2)) The analysis projected publication of a final rule in 2024. Therefore, for purposes of its analysis, DOE used 2029 as the first year of compliance with any amended standards for MREFs.

To calculate consumer product costs, DOE multiplied the MSPs developed in the engineering analysis by the markups described previously (along with sales taxes). DOE used different markups for baseline products and higher-efficiency products because DOE applies an incremental markup to the increase in MSP associated with higher-efficiency products.

DOE is not aware of any data suggesting that installation, maintenance, or repair cost changes as a function of efficiency for MREF products. DOE therefore assumed that installation, maintenance, and repair costs do not impact the LCC or PBP.

Economic literature and historical data suggest that the real costs of many products may trend downward over time according to "learning" or "experience" curves. Experience curve analysis implicitly includes factors such as efficiencies in labor, capital investment, automation, materials prices, distribution, and economies of scale at an industry-wide level.[10] However, due to the lack of historical price data specific to MREFs, DOE used a constant price assumption to project prices of baseline products and more efficient products to the compliance date of the standard. Thus, projected MREF prices for the LCC and PBP analysis are equal to the 2020 values for each efficiency level in each product class.

To accurately estimate the share of consumers that would be affected by a potential energy conservation standard at a particular efficiency level, DOE's LCC analysis considered the projected distribution (market shares) of product efficiencies under the no-new-standards case (*i.e.*, the case without amended or new energy conservation standards). For MREFs, DOE estimated the no-new standards case efficiency distribution based on model counts from DOE's CCMS database. Models in the database were categorized by capacity and assigned an efficiency level based on reported energy use. DOE assumed the current efficiency distribution would be representative of the efficiency distribution in 2029 in the no-new-standards case.

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[10] Taylor, M. and Fujita, K.S. Accounting for Technological Change in Regulatory Impact Analyses: *The Learning Curve Technique*. LBNL-6195E. Lawrence Berkeley National Laboratory, Berkeley, CA. April 2013. http://escholarship.org/uc/item/3c8709p4#page-1.

2.9 SHIPMENTS ANALYSIS

DOE uses projections of product shipments to calculate the national impacts of standards on energy use, NPV, and future manufacturer cash flows. DOE used a stock-accounting method to estimate shipments to market segments that contribute to overall product demand. DOE developed shipments estimates for each product class considered in this preliminary analysis using various data and assumptions. Details on the shipments analysis are provided in chapter 9 of this TSD.

For coolers, DOE assumed the same product saturation rates as developed in the October 2016 Direct Final Rule (81 FR 75194) and applied them to the national housing stocks to derive the stock of in-service cooler products. DOE then estimated the number of new shipments by combining the estimates of stocks with product lifetime estimates developed in the LCC analysis. For combination cooler refrigeration products, DOE used feedback from manufacturers and available models existing in DOE's CCMS database.

To project future shipments, DOE estimated that shipments would increase in line with the increase in housing stock in the U.S. For coolers, DOE assumed that the saturation rates would remain constant projecting forward to 2056. DOE projected the stock of coolers by multiplying the total number of household estimates from the DOE's Energy Information Administration (EIA)'s *Annual Energy Outlook 2021 (AEO 2021)* forecasts with the product saturations. DOE then determined the shipment projections by dividing the projected stock by the mean product lifetime as developed in the LCC analysis. Shipment projections for combination coolers were estimated by applying the housing stock growth rates derived from *AEO 2021* to the shipment estimates for the compliance year.

In response to the December 2020 EA RFI, AHAM collected and provided MREF shipments from AHAM members from 2016 through 2020. AHAM noted that the provided shipments did not include shipments from the full industry but stated that they accounted for a significant portion of the MREF market. Based on these data, AHAM stated that MREF shipments are significantly lower than those estimated under the October 2016 Direct Final Rule. (AHAM, No. 3, p. 2).

DOE reviewed the AHAM-submitted shipments data as well as other historic AHAM-submitted shipments and available data sources to evaluate shipments for MREFs. DOE notes that AHAM did not specify whether the AHAM shipments data included the entirety of the AHAM membership, or whether these data reflect shipments from a subset of AHAM members. To estimate the fraction of AHAM-member shipments compared to the rest of the industry, DOE reviewed its CCMS database and estimated that for freestanding compact and freestanding coolers (which make up the vast majority of the MREF market), approximately 25 percent of available models correspond to AHAM members. DOE also reviewed the TraQline wine chiller data and estimated that approximately 23 percent of wine chiller consumers (over 10 years of historical data) purchased MREFs made by AHAM members.

Based on these market share estimates, and given the uncertainty associated with the AHAM data, for this preliminary analysis DOE has decided to retain the overall shipments methodology and assumptions of the October 2016 Direct Final Rule and the resulting MREF shipments. DOE is requesting comment on this approach and data on the overall shipments for MREFs.

For this preliminary analysis, DOE assumed that market shares between product classes would remain fixed throughout the analysis period. However, DOE recognizes that consumers may choose amongst product classes that offer similar utility.

The current distribution across efficiency levels was estimated for each product class using model counts from DOE's CCMS database. In the no-new-standards case, DOE assumed the efficiency distribution would remain fixed over the course of the analysis period. For standards cases, DOE assumed the market share for efficiency levels that did not meet the standard would "roll-up" to the minimum level that meets the standard in the assumed compliance year (2029). Market shares across efficiency levels (in the no standards case and the standards cases) were assumed to be fixed following the implementation of a standard.

Chapter 9 of this TSD provides additional details regarding the shipments analysis.

2.10 NATIONAL IMPACT ANALYSIS

The NIA provides DOE's assessment of the aggregate impacts of potential energy conservation standards at the national level. Measures of impact that DOE will report include future NES from a standard set at each evaluated efficiency level ("EL") (*i.e.*, the cumulative energy savings from a potential energy conservation standard relative to a no-new-standards case that assumes no change in the standard over a specific forecast period), and the NPV for consumers in the aggregate from a standard set at each EL. To avoid counting a decrease in shipments due to the implementation of a standard as a decrease in energy consumption, NES and NPV are calculated relative to the standard-case shipments.

In its analysis, DOE analyzes the energy and economic impacts of a potential standard on all product classes in the scope of MREFs. Non-representative product classes (*i.e.*, those not analyzed in the engineering, energy-use, and LCC analyses) are scaled using results for the analyzed product class that best represents each non-representative product class.

DOE typically accounts for the direct rebound effect in its NES analysis. The direct rebound effect is the concept that as appliances become more efficient, consumers use more of their service because their operating cost is reduced. However, in the case of refrigeration products such as MREFs, these devices are always in an operational state and DOE does not expect consumers to change their behavior in the presence of a more efficient refrigeration product. As such, DOE assumed no direct rebound effect from the purchase of a more efficient product.

2.10.1 National Energy Savings

The inputs for determining the national energy savings for each product class are: (1) shipments; (2) annual energy consumption per unit; (3) stock of MREFs in each year; (4)

national energy consumption; and (5) site-to-primary energy and fuel-full-cycle conversion factors. DOE calculated the national energy consumption by multiplying the number of units (stock) of each product (by vintage or age) by the unit energy consumption (also by vintage). Vintage represents the age of the product. DOE calculated annual NES based on the difference in national energy consumption for the no-new-standards case and the candidate standards cases for MREFs shipped during the 30-year analysis period (2029 – 2058).

NEEA encouraged DOE to proceed with revising the energy conservation standards for MREFs, and estimated that 33% of site energy (0.14 quads) can be cost-effectively saved over 30 years. (NEEA, No. 7, p. 2).

DOE is not establishing energy conservation standards in this preliminary analysis. Under EPCA, any new or amended energy conservation standard must be designed to achieve the maximum improvement in energy efficiency that DOE determines is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) Furthermore, the new or amended standard must result in a significant conservation of energy. (42 U.S.C. 6295(o)(3)(B)) DOE is publishing this preliminary analysis to collect data and information to inform its decision consistent with its obligations under EPCA. NIA results for this preliminary analysis are presented in detail in chapter 10 of this TSD.

2.10.2 Net Present Value

The inputs for determining NPV are: (1) total annual installed cost; (2) total annual savings in operating costs; and (3) a discount factor to calculate the present value of costs and savings. DOE calculated net savings each year as the difference between the no-new-standards case and each standards case in terms of total savings in operating costs versus total increases in installed costs. DOE calculated savings over the lifetime of MREFs shipped in the 30-year analysis period (2029 – 2058). DOE calculates increases in total installed costs as the difference in total installed cost between the no-new-standards case and standards case (*i.e.*, once the standards take effect).

DOE expresses savings in operating costs as decreases associated with the lower energy consumption of products bought in the standards case compared to the no-new-standards case. Total savings in operating costs are the product of savings per unit and the number of units of each vintage that survive in a given year. Energy cost savings are calculated using the estimated energy savings in each year and the projected price of the appropriate form of energy. To estimate energy prices in future years, DOE multiplied the average national marginal electricity prices by the projection of annual national-average residential or commercial electricity price trends in the Reference case from *AEO 2021*, which has an end year of 2050. DOE set the electricity price of years after 2050 equal to the 2050 value.

DOE calculated NPV as the difference between the present value of operating-cost savings and the present value of total installed costs. DOE used a discount factor based on real discount rates of 3 and 7 percent to discount future costs and savings to present values for the year 2021.

Chapter 10 of this TSD provides additional details regarding the NIA.

2.11 CONSUMER SUBGROUP ANALYSIS

The consumer subgroup analysis (chapter 11 of this TSD), which DOE will conduct if it proceeds with a NOPR, evaluates economic impacts on selected groups of consumers. A consumer subgroup comprises a subset of the population that may be affected disproportionately by amended energy conservation standards (*e.g.*, low-income consumers, seniors). The purpose of a subgroup analysis is to determine the extent of any such disproportional effect. DOE will work with stakeholders to identify any subgroups for consideration.

In comparing potential effects on the different consumer subgroups, DOE will use appropriate values for the inputs that affect the LCC and PBP, such as discount rates and electricity prices. For more detail on the approach to the subgroup analysis, see chapter 11 of this TSD.

2.12 MANUFACTURER IMPACT ANALYSIS

The MIA serves to identify and quantify the impacts of any new or amended energy conservation standards on manufacturers. The MIA will have both quantitative and qualitative aspects, and it will include the analyses of projected industry cash flows, the industry net present value, conversion costs, and direct employment. Additionally, the MIA will seek to describe how new or amended energy conservation standards might affect manufacturing capacity and competition, as well as how standards contribute to overall regulatory burden. Finally, the MIA will seek to identify any disproportionate impacts on manufacturer subgroups, including small business manufacturers. The Department will analyze the impact of standards on manufacturers with substantial input from manufacturers and other interested parties. This section describes the principles that will be used in conducting future manufacturing impact analyses.

DOE conducts the MIA in three phases, and further tailors the analytical framework based on the comments it receives. In Phase I, DOE creates an industry profile to characterize the industry and identify important issues that require consideration. In Phase II, DOE prepares an industry cash-flow model and considers what information it might gather in manufacturer interviews, if conducted. In Phase III, DOE interviews manufacturers and assesses the impacts of standards both quantitatively and qualitatively. DOE assesses industry and subgroup cash flows and industry net present value (“INPV”) using the Government Regulatory Impact Model (“GRIM”). DOE then assesses impacts on competition, manufacturing capacity, direct employment, and cumulative regulatory burden based on manufacturer interview feedback and discussions.

As part of the preliminary analysis, DOE collects, evaluates, and reports preliminary industry information. Chapter 12 of this TSD provides details on the MIA methodology and the preliminary MIA findings.

In response to the December 2020 EA RFI, the CA IOUs commented that the impact of cumulative regulatory burden will likely be greatly reduced compared to the last rulemakings for refrigeration products (2014 for commercial refrigeration products, 2011 for consumer refrigerators, refrigerator-freezers, and freezers). The CA IOUs claimed the regulatory landscape has changed significantly since DOE last considered higher efficiency standards, and suggested that DOE should re-investigate these cumulative regulatory impacts since they may have been eliminated or significantly reduced. (CA IOUs, No. 5, p. 3)

DOE will evaluate and consider the impact of multiple product-specific regulatory actions on MREF manufacturers in any subsequent NOPR analysis. In accordance with the Process Rule,[11] DOE will review product-specific Federal regulations that occur within approximately three years of the proposed compliance date that impose significant impacts on the same manufacturers.

2.13 EMISSIONS IMPACT ANALYSIS

The emissions impact analysis, which is conducted in the NOPR phase, consists of two components. The first component estimates the effect of potential energy conservation standards on power sector and site (where applicable) combustion emissions of CO_2, NO_X, SO_2, and Hg. The second component estimates the impacts of potential standards on emissions of two additional greenhouse gases, methane ("CH_4") and nitrous oxide ("N_2O"), as well as the reductions to emissions of all species due to "upstream" activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions.

The analysis of power sector emissions uses marginal emissions factors that are derived from data in the most recent publication of *AEO*. The methodology is described in chapter 13 and 15 of this TSD. Combustion emissions of CH_4 and N_2O are estimated using emissions intensity factors published by the EPA. The Full Fuel Cycle upstream emissions are estimated based on the methodology described in chapter 15 of this TSD. The upstream emissions include both emissions from fuel combustion during extraction, processing, and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

The emissions intensity factors are expressed in terms of physical units per megawatt-hour ("MWh") or MMBtu of site energy savings. Total emissions reductions will be estimated using the energy savings calculated in the NIA.

2.14 MONETIZATION OF EMISSIONS REDUCTION BENEFITS

DOE considers the estimated monetary benefits likely to result from the reduced emissions of CO_2, CH_4, N_2O, sulfur dioxide ("SO_2"), and NO_X that are project to result from each of the potential standard levels considered.

For the greenhouse gases CO_2, CH_4, and N_2O, DOE estimates the monetized benefits of the reduction in emissions by using a measure of the social cost of each pollutant. These

[11] See 10 CFR 430, Subpart C, Appendix A.

estimates represent the monetary value of the net harm to society associated with a marginal increase in emissions of these pollutants in a given year, or the benefit of avoiding that increase. These estimates are intended to include (but are not limited to) climate-change-related changes in net agricultural productivity, human health, property damages from increased flood risk, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services.

The social cost estimates used by DOE are consistent with the interim estimates issued under Executive Order 13990, "Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis," 86 FR 7037 (Jan. 25, 2021).[12]

To estimate the monetary value of reduced NO_X and SO_2 emissions from electricity generation attributable to the standard levels it considers, DOE uses benefit-per-ton estimates derived from analysis conducted by the EPA. For NO_X and SO_2 emissions from combustion at the site of product use, DOE uses another set of benefit-per-ton estimates published by the EPA.

Further detail on emissions monetization is provided in chapter 14 of this TSD.

2.15 UTILITY IMPACT ANALYSIS

To estimate the impacts of potential energy conservation standards on the electric utility industry, DOE used published output from the National Energy Modeling System ("NEMS") associated with the *AEO*. NEMS is a large, multi-sectoral, partial-equilibrium model of the U.S. energy sector that EIA has developed over several years, primarily for the purpose of preparing the *AEO*. NEMS produces a widely recognized forecast for the United States through 2050 and is available to the public.

DOE uses a methodology based on results published for the *AEO* Reference case, as well as a number of side cases that estimate the economy-wide impacts of changes to energy supply and demand. DOE estimates the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards. DOE uses the side cases to estimate the marginal impacts of reduced energy demand on the utility sector. These marginal factors are estimated based on the changes to electricity sector generation, installed capacity, fuel consumption and emissions in the *AEO* Reference case and various side cases. The methodology is described in more detail in chapter 15 of this TSD.

The output of this analysis is a set of time-dependent coefficients that capture the change in electricity generation, primary fuel consumption, installed capacity and power sector emissions due to a unit reduction in demand for a given end use. These coefficients are

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[12] See Interagency Working Group on Social Cost of Greenhouse Gases, Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide. Interim Estimates Under Executive Order 13990, Washington, D.C., February 2021. www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf?source=email.

multiplied by the stream of electricity savings calculated in the NIA to provide estimates of selected utility impacts of new or amended energy conservation standards.

2.16 EMPLOYMENT IMPACT ANALYSIS

The adoption of amended energy conservation standards can affect employment both directly and indirectly. Direct employment impacts are changes in the number of employees at the plants that produce the covered products. DOE evaluates direct employment impacts in the MIA.

Indirect employment impacts may result from expenditures shifting between goods (the substitution effect) and changes in income and overall expenditure levels (the income effect) that occur due to standards. DOE defines indirect employment impacts from standards as net jobs eliminated or created in the general economy as a result of increased spending driven by increased product prices and reduced spending on energy.

The indirect employment impacts are investigated in the employment impact analysis using the Pacific Northwest National Laboratory's "Impact of Sector Energy Technologies" ("ImSET") model[13]. The ImSET model was developed for DOE's Office of Planning, Budget, and Analysis to estimate the employment and income effects of energy-saving technologies in buildings, industry, and transportation. Compared with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy conservation investments.

2.17 CANDIDATE ENERGY CONSERVATION STANDARD LEVELS

DOE received comments from stakeholders regarding changes to the stringency of the current standards for MREFs in general.

AHAM commented that amended standards for MREFs are not likely to be justified under EPCA due to a low number of shipments and no new technology allowing for meaningful energy savings per unit. AHAM stated that MREFs already use very little energy, so the potential for national energy savings would be low. (AHAM, No. 3, pp. 1-2) AHAM urged DOE to determine that no amended standard is justified for MREF products because efficiency improvements will result in additional costs for manufacturers and consumers and are not likely to be justified by energy savings. (AHAM, No. 3, p. 3)

GEA agreed with the statements from AHAM, adding that the shipment levels and low energy consumption of MREFs mean that any increase in stringency would not have sufficient impact on energy consumption to justify the costs. (GEA, No. 6, p. 1)

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[13] Livingston, O. V., S. R. Bender, M. J. Scott, and R. W. Schultz. *ImSET 4.0: Impact of Sector Energy Technologies Model Description and User Guide.* 2015. Pacific Northwest National Laboratory: Richland, WA. PNNL-24563.

Sub Zero asserted that requiring efficiency improvements will result in additional costs for manufacturers and consumers, and that these costs are not likely to be balanced by significant energy savings due to low shipments. Sub Zero suggested that no amended standards are justified for MREF products at this time, but DOE could evaluate in the future if shipments have increased and whether there is a significant energy savings opportunity. Sub Zero stated that DOE could prioritize other rulemakings that will have more significant energy savings opportunities. (Sub Zero, No. 8, p. 1) Regarding built-in products specifically, Sub Zero commented that the separate product classes for built-in and freestanding products were established to permit different future standards levels for the different classes, and they believe the analysis will show the need for built-in credits to equalize the impact of standards on consumers, as well as on manufacturers. (Sub Zero, No. 8, p. 2)

The CA IOUs, commented that DOE's CCMS Database for MREFs lists a significant number of products that exceed the current standard levels by at least ten percent, with several products exceeding the previous maximum technologically feasible (max-tech) levels for the freestanding compact product class. The CA IOUs supported DOE analyzing updated energy conservation standards for MREFs and stated that it is likely a new rulemaking would be economically justified, technologically feasible, and result in significant savings of energy. (CA IOUs, No. 5, pp. 1-2) ASAP similarly commented that DOE's CCMS Database indicates that there may be significant opportunity to improve the efficiency of MREFs. (ASAP, No. 4, p. 1)

NEEA presented an analysis on the potential 30-year energy savings from increased stringency of energy conservation standards for MREFs and urged DOE to consider candidate standard levels beyond the max-tech efficiency levels considered in the previous rulemaking. (NEEA, No. 7, pp. 2, 5) NEEA concluded that available data on cost effectiveness supports NEEA's assertion that a standards update to include more efficient MREF technologies is both timely and appropriate. Specifically, NEEA encouraged DOE to proceed with a revision to the MREF standards and estimated that 33% of site energy (0.14 quads) can be cost-effectively saved over 30 years. NEEA's estimate was based on an analysis of cooler product classes. NEEA assessed the potential energy savings corresponding to an efficiency level equivalent to the 90th percentile of product efficiency (disaggregated into four separate volume categories) determined from DOE's CCMS Database, using shipments and product lifetime data from DOE's previous rulemaking. (NEEA, No. 7, pp. 2 & 11-13)

DOE evaluates the significance of energy savings on a case-by-case basis. DOE estimates a combined total of 0.45 quads of FFC energy savings at the max-tech efficiency levels for MREFs. This represents 44.4 percent energy savings relative to the no-new-standards case energy consumption for MREFs. DOE has initially determined that the energy savings for the candidate standard levels considered in this preliminary analysis are "significant" within the meaning of 42 U.S.C. 6295(o)(3)(B).

In terms of process, DOE specifies candidate standard levels ("CSLs") in the preliminary analysis, but it does not propose particular standards at this stage of the rulemaking. Pursuant to the Process Rule,[14] CSLs are selected based on the following considerations:

(1) Costs and savings of design options. Design options that have payback periods that exceed the median life of the product or which result in life-cycle cost increases relative to the base case, using typical fuel costs, usage, and private discount rates, will not be used as the basis for CSLs.
(2) Further information on factors used for screening design options. If further information or analysis leads to a determination that a design option, or a combination of design options, has unacceptable impacts under statutory criteria or implementing policies provided in the Process Rule, that design option or combination of design options will not be included in a CSL.
(3) Selection of CSLs. CSLs, which will be identified in the pre-NOPR documents and on which impact analyses will be conducted, will be based on the remaining design options.

Section 7(c)(1)-(3) of the Process Rule.

The range of CSLs will typically include the most energy-efficient combination of design options, the combination of design options with the lowest life-cycle cost, and a combination of design options with a payback period of not more than three years. Section 7(c)(3)(i) of the Process Rule. CSLs that incorporate noteworthy technologies or fill in large gaps between efficiency levels of other CSLs also may be selected. Section 7(c)(3)(ii) of the Process Rule.

For this preliminary analysis, DOE constructed CSLs based on the range of efficiency levels analyzed. The analyzed efficiency levels typically represent similar market efficiency levels (*e.g.*, efficiency level 1 represents the ENERGY STAR level for both analyzed cooler product classes; efficiency level 5 represents max-tech), so DOE grouped the same efficiency levels in determining CSL results. For combination cooler refrigeration products, DOE analyzed only four efficiency levels beyond the baseline, so the max-tech efficiency level was considered for CSLs 4 and 5.

If, following review of the comments received in response to this preliminary analysis, DOE determines it is appropriate to proceed to a NOPR, DOE will refine its final selection of CSLs for further analysis after any revision of the preliminary analyses.

2.18 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE prepares an analysis that evaluates potential non-regulatory policy alternatives, comparing the costs and benefits of each to those of the proposed standards. DOE recognizes that non-regulatory policy alternatives can substantially affect energy efficiency

[14] See 10 CFR 430, Subpart C, Appendix A.

or reduce energy consumption. DOE bases its assessment on the actual impacts of any such initiatives to date, but also considers information presented by interested parties regarding the potential future impacts of current initiatives.

2.19 DEPARTMENT OF JUSTICE REVIEW

Section 325(o)(2)(B)(i)(V) of EPCA states that, before the Secretary of Energy may prescribe a new or amended energy conservation standard, the Secretary shall ask the U.S. Attorney General to make a determination of "the impact of any lessening of competition…that is likely to result from the imposition of the standard." (42 U.S.C. 6295) Pursuant to this requirement, DOE solicits the views of the U.S. Department of Justice on any lessening of competition that is likely to result from the imposition of a proposed standard and gives the views provided full consideration in assessing economic justification of a proposed standard.

CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter of the technical support document ("TSD") provides a preliminary assessment of the miscellaneous refrigeration product ("MREF") industry in the United States. The U.S. Department of Energy ("DOE") developed the market and technology assessment presented in this chapter primarily from publicly available information and comments received from interested parties in response to an early assessment review and request for information ("RFI") published by DOE on December 8, 2020 (the "December 2020 Early Assessment Review RFI") to initiate a review to determine whether any new or amended standards for MREFs would be appropriate. 85 FR 78964.

This market and technology assessment identifies the manufacturers and their product characteristics, which form the basis for the engineering and the life-cycle cost ("LCC") analyses. Present and past industry structure and industry financial information help DOE in the process of conducting the manufacturer impact analysis. This assessment also identifies the range of technologies that could improve the efficiencies of MREFs, which DOE considers further in the subsequent stages of its analysis.

3.1.1 Product Definitions

Title 10 of the Code of Federal Regulations ("CFR"), part 430.2, includes the product definitions for MREFs as follows:

- *Miscellaneous refrigeration product* means a consumer refrigeration product other than a refrigerator, refrigerator-freezer, or freezer, which includes coolers and combination cooler refrigeration products.

- *Cooler* means a cabinet, used with one or more doors, that has a source of refrigeration capable of operating on single-phase, alternating current and is capable of maintaining compartment temperatures either:
    1) No lower than 39 °F (3.9 °C); or
    2) In a range that extends no lower than 37 °F (2.8 °C) but at least as high as 60 °F (15.6 °C) as determined according to the applicable provisions in 10 CFR §429.61(d)(2).

- *Built-in compact cooler* means any cooler with a total refrigerated volume less than 7.75 cubic feet and no more than 24 inches in depth, excluding doors, handles, and custom front panels, that is designed, intended, and marketed exclusively to be:
    1) Installed totally encased by cabinetry or panels that are attached during installation;
    2) Securely fastened to adjacent cabinetry, walls or floor;
    3) Equipped with unfinished sides that are not visible after installation; and
    4) Equipped with an integral factory-finished face or built to accept a custom front panel.

- *Built-in cooler* means any cooler with a total refrigerated volume of 7.75 cubic feet or greater and no more than 24 inches in depth, excluding doors, handles, and custom front panels; that is designed, intended, and marketed exclusively to be:
    1) Installed totally encased by cabinetry or panels that are attached during installation;
    2) Securely fastened to adjacent cabinetry, walls or floor;
    3) Equipped with unfinished sides that are not visible after installation; and
    4) Equipped with an integral factory-finished face or built to accept a custom front panel.

- *Freestanding compact cooler* means any cooler, excluding built-in compact coolers, with a total refrigerated volume less than 7.75 cubic feet.

- *Freestanding cooler* means any cooler, excluding built-in compact coolers, with a total refrigerated volume of 7.75 cubic feet or greater.

- *Combination cooler refrigeration product* means any cooler-refrigerator, cooler-refrigerator-freezer, or cooler-freezer.

- *Cooler-refrigerator* means a cabinet, used with one or more doors, that has a source of refrigeration that requires single-phase, alternating current electric energy input only, and consists of two or more compartments, including at least one cooler compartment as defined in appendix A of subpart B of 10 CFR §430, where:
    1) At least one of the remaining compartments is not a cooler compartment as defined in appendix A of subpart B of 10 CFR §430 and is capable of maintaining compartment temperatures above 32 °F (0 °C) and below 39 °F (3.9 °C) as determined according to 10 CFR §429.61(d)(2);
    2) The cabinet may also include a compartment capable of maintaining compartment temperatures below 32 °F (0 °C) as determined according to 10 CFR §429.61(d)(2); but
    3) The cabinet does not provide a separate low temperature compartment capable of maintaining compartment temperatures below 8 °F (−13.3 °C) as determined according to 10 CFR §429.61(d)(2).

- *Cooler-all-refrigerator* means a cooler-refrigerator that does not include a compartment capable of maintaining compartment temperatures below 32 °F (0 °C) as determined according to the provisions in 10 CFR §429.61(d)(2). It may include a compartment of 0.50 cubic-foot capacity (14.2 liters) or less for the freezing and storage of ice.

- *Cooler-refrigerator-freezer* means a cabinet, used with one or more doors, that has a source of refrigeration that requires single-phase, alternating current electric energy input only, and consists of three or more compartments, including at least one cooler compartment as defined in appendix A of subpart B of 10 CFR §430, where:
    1) At least one of the remaining compartments is not a cooler compartment as defined in appendix A of subpart B of this part and is capable of maintaining compartment temperatures above 32 °F (0 °C) and below 39 °F (3.9 °C) as determined according to 10 CFR §429.61(d)(2); and

2) At least one other compartment is capable of maintaining compartment temperatures below 8 °F (−13.3 °C) and may be adjusted by the user to a temperature of 0 °F (−17.8 °C) or below as determined according to 10 CFR §429.61(d)(2).

- *Cooler-freezer* means a cabinet, used with one or more doors, that has a source of refrigeration that requires single-phase, alternating current electric energy input only, and consists of two or more compartments, including at least one cooler compartment as defined in appendix A of subpart B of 10 CFR §430, where the remaining compartment(s) are capable of maintaining compartment temperatures at 0 °F (−17.8 °C) or below as determined according to the provisions in 10 CFR §429.61(d)(2).

3.2 MARKET ASSESSMENT

3.2.1 Product Classes

The Energy Policy and Conservation Act (“EPCA”),[a] (42 U.S.C. 6291–6317), requires that DOE establish separate standards for a group of covered products (*i.e.*, establish a separate product class) if DOE determines that separate standards are justified based on the type of energy used, or if DOE determines that a product’s capacity or other performance-related feature justifies a different standard. (42 U.S.C. 6295(q)(1)(A) and (B))In making a determination whether a performance related feature justifies a different standard, DOE must consider factors such as the utility to the consumer of the feature and other factors DOE determines are appropriate. (42 U.S.C. 6295(q)(1)) DOE currently separates MREFs into multiple product classes that are subject to energy conservation standards.

3.2.1.1 Current Product Classes

Energy conservation standards were adopted for MREFs in a direct final rule published in 2016 (the “October 2016 Direct Final Rule”). 81 FR 75194 (October 28, 2016). The October 2016 Direct Final Rule established the current product classes and energy conservation standards specified at 10 CFR §430.32(aa). *Id*. As per the CFR, there are 12 product classes based on the following characteristics: type of unit (cooler, cooler-all-refrigerator, or cooler-freezer[b]), total refrigerated volume (standard or compact), the compartment temperature ranges for any non-cooler compartments, and any relevant product features (*e.g.*, configuration, defrost type, ice making, *etc.*).

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[a] All references to EPCA in this document refer to the statute as amended through the Energy Act of 2020, Public Law 116–260 (Dec. 27, 2020).

[b] In the October 2016 Direct Final Rule established eight product classes for combination cooler refrigeration products which represented the products which were either available on the market or very similar to products available at the time of the rulemaking. Product classes for other combinations were considered, but not adopted, due to lack of product availability at the time. 81 FR 75194, 75210.

Table 3.2.1 summarizes the 12 current MREF product classes with energy conservation standards.

Table 3.2.1 Product Classes for MREFs

No.	Product Class
Cooler-BC	Built-in compact cooler
Cooler-B	Built-in cooler
Cooler-FC	Freestanding compact cooler
Cooler-F	Freestanding cooler
C-3A	Cooler with all-refrigerator - automatic defrost
C-3A-BI	Built-in cooler with all-refrigerator - automatic defrost
C-9	Cooler with upright freezers with automatic defrost without an automatic icemaker
C-9-BI	Built-in cooler with upright freezer with automatic defrost without an automatic icemaker
C-9I	Cooler with upright freezer with automatic defrost with an automatic icemaker
C-9I-BI	Built-in cooler with upright freezer with automatic defrost with an automatic icemaker
C-13A	Compact cooler with all-refrigerator - automatic defrost
C-13A-BI	Built-in compact cooler with all-refrigerator - automatic defrost

3.2.1.2 Potential Product Class Modifications

DOE conducted this preliminary analysis based on the existing product classes. However, the engineering analysis only focused on certain product classes representative of the market and representative of the other product classes not directly analyzed. See chapter 5 of this TSD. DOE acknowledges there may be an opportunity to decrease the number of product classes in DOE's regulations, but additional product classes may be needed to address other product configurations available or that may become available on the market.

Product Classes with Automatic Icemakers

For MREFs manufactured on or after October 28, 2019, DOE's test procedures specify a constant energy-use adder of 84 kWh/year (by use of a 0.23 kWh/day adder; see section 5.3(a)(ii) of Appendix A), which represents the annual energy consumed by automatic icemakers in MREFs. With this constant adder, the standard levels for product classes with an automatic icemaker are equal to the standards of their counterparts without an icemaker plus the 84 kWh/year. In a recent test procedure final rule, DOE amended the icemaking energy consumption adder from 84 kWh/yr to 28 kWh/yr after having determined that the revised adder would more accurately reflect energy use during a representative average use cycle. This amendment will go into effect with a subsequent final rule amending the energy conservation standards in order to avoid substantial re-certification and re-labeling costs to manufacturers and private labelers. 86 FR 56790, 56815 (Oct. 12, 2021). With the continued use of a constant icemaker adder, the standard levels for product classes with an automatic icemaker would continue to be equal to the standards of their counterparts without an icemaker, plus the adder.

Because the standards for the product classes with and without automatic icemakers are effectively the same, except for the constant adder, there may be an opportunity to merge product classes to reduce the total number of overall product classes for MREFs. The energy consumption associated with the automatic icemaking could then be incorporated into product labeling rather than the energy conservation standard. For example, if no additional product classes for MREFs were to be adopted, this would result in the combination of product classes C-9I with C-9 and C-9I-BI with C-9-BI.

Additional Combination Cooler Refrigeration Product Configurations

The eight current product classes for combination cooler refrigeration products represent the product configurations considered during the analysis for the October 2016 Direct Final Rule.However, manufacturers could offer combination cooler refrigeration products with configurations corresponding to any of the 42 existing refrigerator, refrigerator-freezer, and freezer product classes (see 10 CFR 430.32(a)) – *i.e.*, adding a cooler compartment to any of the existing 42 product configurations. If any new product configurations were to become available on the market, they may require new product classes and corresponding MREF energy conservation standards.

DOE would consider whether such new product classes would be appropriate as part of any subsequent NOPR and welcomes comment on any likely product configurations and how DOE could consider such products in its analysis. DOE has provided a preliminary discussion of the engineering analysis approach that could be considered for any new combination cooler refrigeration products in chapter 5 of this TSD.

Produce Growers

As discussed in chapter 2 of this TSD, DOE is aware that there are new products entering the market which are designed to grow produce (such as microgreens or vegetables) indoors. DOE understands that these types of products (referred to herein as "produce growers") are marketed for use in homes. Based on a review of the market, the major components in a produce grower generally are: an enclosed cabinet with a door, a hydration system to water the plants, grow lights, and fans to circulate air. The hydration system may be manual (such as a water tray that is manually refilled) or automatic (such as a hydroponic pump system). Grow lights used in product growers are typicaly LEDs and may be tuned to provide the specific wavelengths of light most important for photosynthesis.

Some of these products utilize refrigeration systems to maintain internal compartment conditions that are conducive to growing plants. See, for example, discussion of one such product by GE Appliances, a Haier Company ("GEA"), at 86 FR 35766 (July 7, 2021). This cooler is equipped with systems to provide hydration and lighting for the growth of indoor plants. Because the cabinet is an enclosed space, these operations cause the interior air temperature and humidity to rise to levels which are not conducive to healthy plant growth, and thus a vapor-compression cooling system is used to cool the cabinet. However, the product is not capable of maintaining a temperature as low as 55 °F when subject to an ambient temperature of 90 °F.

As stated in response to GEA's initial petition for waiver, based on GEA's description of the model, DOE determined that the basic model meets the definition of a cooler in 10 CFR 430.2 for the following reasons: 1) the product consists of a cabinet used with one or more glass doors, as specified by GEA; and 2) the product maintains compartment temperatures no lower than 39 °F, as determined when tested in a 90 °F ambient temperature. 86 FR 35766, 35768.

Although a produce grower may meet the definition of a cooler, as with GEA's product, DOE notes that produce growers are distinctly different from other coolers intended to store food or beverages. DOE acknowledges the significant differences between this basic model and typical MREFs (and more specifically, coolers).[c] DOE did not consider such products when establishing energy conservation standards for coolers or the potential design options that could be used to reduce energy consumption, which are likely very different than those considered for coolers generally. (See chapter 3 of the October 2016 Direct Final Rule TSD)

DOE is not aware of any other products, besides the GEA model, currently on the market that utilize an active refrigeration system to maintain cabinet conditions for plant growth. However, DOE acknowledges that these products may represent a growing market and more models may become available. Accordingly, DOE may consider produce growers as a distinct category of MREFs when considering potential future energy conservation standards.

To determine whether and how to address such products, DOE is seeking information regarding the emergence of produce growers available on the market, typical usage patterns and energy use (and corresponding test procedures), and any technologies available to reduce their energy consumption.

3.2.2 Product Test Procedures

DOE's current test procedure for MREFs is located at 10 CFR §430, Subpart B, Appendix A ("Appendix A"). This test procedure originally only covered refrigerators and refrigerator-freezers and was the result of numerous evolutionary steps taken since DOE initially established its test procedures for these products in a final rule published in the *Federal Register* on September 14, 1977. 42 FR 46140. A detailed history of the Appendix A test procedure is provided in chapter 3 of DOE's preliminary analysis technical support document for energy conservation standards for refrigerators, refrigerator-freezers, and freezers, found online at www.regulations.gov/docket/EERE-2017-BT-STD-0003-0020.

On July 18, 2016, DOE published a final rule (the "July 2016 Final Rule") that established coverage and test procedures for MREFs. 81 FR 46768. Included within this category were refrigeration products that include one or more compartments that maintain higher temperatures than typical refrigerator compartments, such as wine chillers and beverage coolers. Additionally, the July 2016 Final Rule amended Appendix A to include provisions for testing MREFs and to improve the clarity of certain existing test requirements. *Id*.

Most recently, on October 12, 2021, DOE adopted amendments to the test procedures for consumer refrigeration products (the "October 2021 Test Procedure Final Rule"). 86 FR 56790 (Oct. 12, 2021). The October 2021 Test Procedure Final Rule incorporates by reference the current revision to the applicable industry standard, AHAM HRF-1-2019, "Energy and Internal Volume of Consumer Refrigeration Products," which includes updates to methods for test setup, sampling intervals, test conditions, and energy consumption calculations. In this update, DOE amended the test procedures for consumer refrigeration products to 1) adopt a permanent,

[c] GEA stated in its September 17, 2021, petition for waiver that the subject basic model is fundamentally different from all other known MREFs. Specifically, GEA stated that: 1) the product has a fundamentally different purpose than other MREFs, which are for cooling and storing beverages and food; 2) the primary purpose of the refrigeration system in the product is humidity control; 3) because the product operates at or near ambient temperature, the product is uninsulated, unlike all other known MREFs, which are insulated; and 4) the product contains grow lighting, which both consumes energy and adds heat to the product. (GEA, Document No. EERE-2021-BT-WAV-0009-0006 at p. 4).

constant automatic icemaker energy use adder of 28 kWh/yr, and 2) require that units shipped with communication devices (including those for demand-response functions) shall be tested with the communication device on but not connected to any communication network. Specific instructions regarding test setup and energy use calculations for products with multiple compressors and variable defrost controls are also provided.

DOE conducted this preliminary analysis using an approach that would be applicable to both the current DOE test procedure and the amended test procedure specified by the October 2021 Test Procedure Final Rule. As discussed in chapter 5 of this TSD, DOE's engineering analysis considered MREF performance exclusive of any automatic icemaker energy use contribution. Additionally, icemaking energy use is only relevant for combination cooler refrigeration products with automatic icemakers.

3.2.3 Manufacturer Information

This section provides information on manufacturers of MREFs, including manufacturer trade groups (section 3.2.3.1), manufacturer counts (section 3.2.3.2), industry mergers and acquisitions (section 3.2.3.3), and product distribution channels (section 3.2.3.4).

3.2.3.1 Manufacturers Trade Groups

DOE recognizes the importance of trade groups in disseminating information and promoting the interests of the industry that they support. To gain insight into the refrigeration industry that manufactures the products covered in this rulemaking, DOE researched various associations available to manufacturers, suppliers, and users of such equipment.

The Association of Home Appliance Manufacturers ("AHAM") is the primary manufacturer trade group representing manufactures of MREFs. AHAM provides services to its members including government relations; certification programs for refrigeration products; an active communications program; and technical services and research. In addition, AHAM conducts other market and consumer research studies. AHAM also develops and maintains technical performance standards for various appliances to provide uniform, repeatable procedures for measuring specific product characteristics and performance features. Table 3.2.2 lists AHAM members that manufacture MREFs.

Table 3.2.2 AHAM Members that Manufacture MREFs

AHAM Members
AB Electrolux of Sweden
BSH Home Appliances Corporation
Danby Products, Ltd.
Haier Smart Home Co. Ltd.
Hisense International Co. Ltd.
LG Electronics
Liebherr Export AG
Midea Group
Miele, Inc.
Perlick Corporation
Samsung Electronics America, Inc.
Smeg S.p.A
Sub-Zero Group Inc.
The Middleby Corp
Whirlpool Corporation

3.2.3.2 MREF Manufacturers

DOE reviewed the Compliance Certification Management System ("CCMS") database[d], the California Energy Commission's Modernized Appliance Efficiency Database System ("MAEDbS"),[1] retailer websites, and information from the prior MREF rulemaking to identify manufacturers of the covered products. DOE identified 72 companies that import, private label, produce, or manufacture MREFs. DOE notes that it can be difficult to differentiate between companies that import, private label, produce, and manufacture based on public information. Many companies offer a mix of imported, private labeled, and in-house manufactured product. Using available information from manufacturer websites, manufacturer specifications and product literature, site images, and basic model numbers, DOE estimates 26 of these companies are original equipment manufacturers ("OEMs") of covered products. Of the 26 OEMs, DOE estimates five companies have manufacturing facilities producing covered products in the United States.

3.2.3.3 Mergers and Acquisitions

The appliance manufacturing industry has had a continuous history of consolidation. However, despite the overall trend towards consolidation in the home appliance industry, the MREF industry remains relatively fragmented. According to a third-party source, market data from 2016-2021 shows that the top three manufacturers, Haier, Danby, and Avanti (acquired by the Legacy Companies in 2019), comprised around 20 percent of the coolers market share during that time (with Haier accounting for an estimated 10 percent of the total market).[2,e]

Recent mergers and acquisitions ("M&A") relating to the MREF market include M&A of both large appliance manufacturers and smaller, specialty appliance manufacturers. In 2014, Whirlpool acquired majority interest in Indesit, purchasing 60.4 percent for an estimated $1.04

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[d] Accessible at www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A*.

[e] A summary of the report is available at www.wboc.com/story/44383134/wine-cooler-refrigerator-market-size-2021-industry-share-cagr-of-38-global-trend-in-depth-manufacturers-analysis-revenue-covid-19-impact-supply.

billion.[3] In the same year, Whirlpool purchased a 51 percent stake in Hefei Sanyo for $552 million.[4] In 2015, Ferguson Enterprise acquired Living Direct, Inc., a specialty appliance manufacturer.[5] Living Direct markets MREFs under its Avallon, Edgestar, and Landmark brands. Samsung Electronics acquired Dacor in 2016 for an undisclosed amount.[6] In 2016, Electrolux acquired Vintec, an Australia and Singapore-based company that sells wine cabinets primarily in the Asia Pacific region.[7] Also in 2016, the Haier Group purchased GE Appliances for $5.6 billion.[8] In 2019, the Legacy Companies acquired Avanti Products, a manufacturer of compact appliances, for an undisclosed amount.[9] The private equity firm, American Securities LLC, acquired Cuisinart and its parent company, Conair Corporation, in 2021 for an undisclosed amount.[10]

3.2.3.4 Distribution Channels

Understanding the distribution channels for MREFs is an important facet of the market assessment. DOE received information regarding the distribution channels for MREFs from manufacturer interviews in the prior MREF rulemaking.

The distribution chain for MREFs is similar to that of other consumer products, as the majority of consumers purchase their appliances directly from retailers. These retailers include; (1) indendent appliance retailers; (2) national “big-box” stores; (3) home improvement and department stores; (4) internet retailers (including big-box store websites); and (5) kitchen remodelers. For coolers, the distribution method tends to vary according to price point, with higher-end products typically being sold by independent retailers and less expensive products being sold by national retailers or online.

3.2.4 Regulatory Programs

The following section details current regulatory programs mandating energy conservation standards for MREFs. It covers U.S. Federal energy conservation standards, State standards, standards in Canada and Mexico (which may impact the companies servicing the North American market), and other international standards.

3.2.4.1 Federal Energy Conservation Standards.

The current energy conservation standards are shown in Table 3.2.3.

Table 3.2.3 Federal Energy Efficiency Standards for MREFs Effective October 28, 2019

No.	Product Class	Maximum Annual Energy Use (kWh/yr)
Cooler-BC	Built-in compact cooler	7.88AV + 155.8
Cooler-B	Built-in cooler	7.88AV + 155.8
Cooler-FC	Freestanding compact cooler	7.88AV + 155.8
Cooler-F	Freestanding cooler	7.88AV + 155.8
C-3A	Cooler with all-refrigerator - automatic defrost	4.57AV + 130.4
C-3A-BI	Built-in cooler with all-refrigerator - automatic defrost	5.19AV + 147.8

No.	Product Class	Maximum Annual Energy Use (kWh/yr)
C-9	Cooler with upright freezers with automatic defrost without an automatic icemaker	5.58AV + 147.7
C-9-BI	Built-in cooler with upright freezer with automatic defrost without an automatic icemaker	6.38AV + 168.8
C-9I	Cooler with upright freezer with automatic defrost with an automatic icemaker	5.58AV + 231.7
C-9I-BI	Built-in cooler with upright freezer with automatic defrost with an automatic icemaker	6.38AV + 252.8
C-13A	Compact cooler with all-refrigerator - automatic defrost	5.93AV + 193.7
C-13A-BI	Built-in compact cooler with all-refrigerator - automatic defrost	6.52AV + 213.1

AV: Adjusted Volume in ft^3

3.2.4.2 State Energy Conservation Standards

As part of its Title 20 Appliance Efficiency Regulations, the California Energy Commission ("CEC") has established standards for MREFs that are harmonized with DOE's energy conservation standards.[11]

3.2.4.3 Canadian Energy Conservation Standards

MREFs are also regulated products in Canada under the Canadian Energy Efficiency Regulations. In June 2019, Canada updated its Energy Standards for refrigerators, refrigerator-freezers, and freezers to harmonize with DOE's current energy conservation standards for these products and MREFs.[12] The regulations reference Canadian Standards Association ("CSA") CAN/CSA-C300-15, *Energy Performance and Capacity of Household Refrigerators, Refrigerator-Freezers, Freezers, and Wine Chillers*, for the testing procedure (which is substantively the same as DOE's test procedure) and for maximum annual energy consumption ("MAEC") limits for MREFs.[13] The product classes and MAEC limits in the Canadian regulations are the same as in the DOE standards.

In April 2021, Canada updated its *Energy Efficiency Regulations* Forward Regulatory Plan[f] to indicate Natural Resources Canada's intent to proceed with the development of amended minimum energy performance standards for several home appliances, including refrigerators, refrigerator-freezers, and freezers. Specifically, the amended standards under consideration would increase the energy efficiency for these products to the current ENERGY STAR level. However, Canada has not indicated that it plans to adopt amended minimum energy performance standards for MREFs.

[f] See www.nrcan.gc.ca/transparency/acts-and-regulations/forward-regulatory-plan/amendments-canadas-energy-efficiency-regulations-2016/21709.

3.2.4.4 Other International Efficiency Standards

According to the Collaborative Labeling and Appliance Standards Program ("CLASP") database, Jamaica, Mauritius, Republic of Korea, the European Union, and the Economic Community of West African States have mandatory efficiency standards for MREFs.[14]

In 2005, the European Parliament adopted a Commission proposal for a directive on establishing a framework for setting eco-design requirements (such as energy efficiency requirements) for all energy-using products in the residential, tertiary (services), and industrial sectors.[15] In October 2019, the European Commission updated its ecodesign requirements for refrigerating appliances (Commission Regulation (EU) 2019/2019) outlining specific requirements regarding household refrigerating appliances up to 1,500 L (~53 ft^3). This regulation specifies a maximum Energy Efficiency Index ("EEI"), a test procedure to calculate a unit's annual energy consumption, labeling requirements, and distinct product categories.[16] These ecodesign measures also include requirements for repairability and recyclability and is effective as of March 1, 2021.

It is difficult to compare the standards in other countries with those in the U.S. due to differences in test procedures. Many international standards reference the International Electrotechnical Standard (IEC) 62552, "Household refrigerating appliances - Characteristics and test methods," either the 2007 or 2015 version. Most notably, both versions of the IEC procedures include a test at a lower ambient temperature compared to Appendix A.

3.2.5 Voluntary and other Federal and State Programs

In addition to mandatory standards, there are voluntary programs as well as other Federal and State policies that affect the efficiency of new MREFs.

3.2.5.1 ENERGY STAR

ENERGY STAR is a voluntary program administered by the U.S. government to promote energy efficient consumer products.

The current ENERGY STAR criteria for refrigeration products, version 5.1, was drafted with input from stakeholders and was released on August 5, 2021. The ENERGY STAR criteria are in terms of reductions in measured energy use compared to the Federal energy conservation standards, and are shown in Table 3.2.4. The ENERGY STAR criteria are only applicable to cooler product classes, as combination cooler refrigeration products are not currently covered by ENERGY STAR. While ENERGY STAR offers a 5% increased energy consumption allowance for connected refrigerators, refrigerator-freezers, and freezers, MREFs do not qualify for this allowance.[17]

Table 3.2.4 ENERGY STAR Criteria for MREFs

Product Class	Maximum Annual Energy Use (kWh/yr)	% Less Energy
Built-in compact cooler	5.52AV + 109.1	30%
Built-in cooler	5.52AV + 109.1	30%
Freestanding compact cooler	6.30AV + 124.6	20%
Freestanding cooler	7.09AV + 140.2	10%

AV: Adjusted Volume in ft^3

3.2.5.2 Federal Energy Management Program

DOE's FEMP[g] works to reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at Federal sites. FEMP helps Federal buyers identify and purchase energy-efficient equipment, including MREFs.

Federal agencies are generally required by the Energy Policy Act of 2005 (EPACT 2005, P.L. 109-58) and Federal Acquisition Regulations ("FAR") Subpart 23.2 to specify and buy ENERGY STAR-qualified products or, in categories with no ENERGY STAR label, FEMP-designated products which are among the highest 25 percent of equivalent products for energy efficiency.

3.2.6 Historical Shipments

Compared to refrigerators, refrigerator-freezers, and freezers, very few data exist for the historical shipments and efficiencies of MREFs. For the October 2016 Direct Final Rule, DOE obtained shipment estimates from AHAM and The NPD Group. DOE also estimated historical shipments using estimates of saturation and product lifetimes. See chapter 3 of the October 2016 Direct Final Rule TSD.

In response to the December 2020 Early Assessment Review RFI, AHAM provided 2016-2020 data for MREF shipments estimates from AHAM-member manufacturers. AHAM noted that its shipment numbers do not include shipments of the full industry, but stated that they do account for a significant portion of it and based on these data, shipments are significantly lower than DOE estimated under its October 2016 Direct Final Rule. (AHAM, No. 3, p. 2)

Additionally, DOE compiled data from Euromonitor.[18] These findings are altogether shown in Table 3.2.5 below. DOE does not currently have data reflecting the historical efficiencies of MREFs. See chapter 9 of this TSD for a discussion of DOE's shipments analysis.

[g] For more information, please visit www.eere.energy.gov/femp.

Table 3.2.5 Historical MREF Shipment Estimates

	Estimated Annual Shipments (millions of units)					
Data Source:	**AHAM**	**NPD Group (Low est.)***	**NPD Group (High est.)***	**Online Surveys***	**Online Surveys (all coolers)**	**Euromonitor***
2005		0.28	0.45	1.07	1.34	
2006		0.75	1.19	1.09	1.37	
2007		1.03	1.64	1.10	1.39	
2008		0.57	0.92	1.11	1.40	
2009		0.46	0.74	1.12	1.41	
2010	0.15	0.46	0.73	1.12	1.41	
2011	0.19	0.42	0.67	1.13	1.42	
2012	0.19			1.14	1.43	0.70
2013	0.20			1.15	1.45	0.76
2014	0.26			1.16	1.46	0.81
2015						0.84
2016	0.09					0.87
2017	0.10					0.89
2018	0.11					
2019	0.10					
2020	0.11					

* Wine coolers only.

DOE estimated that shipments of combination cooler refrigeration products were 36,000 in 2014, based on manufacturer feedback.

3.2.7 Saturation in U.S. Homes

Saturation refers to the percentage of homes with a given product. In the previous rulemaking, DOE obtained estimates on the saturation of coolers from studies that conducted surveys of MREF owners.[19,20] One survey targeted products marketed specifically for the storage of wine and beverages, which found household saturation of 10.6 percent. The technology of these products was estimated to be 85 percent thermoelectric and 15 percent vapor compression. Other surveys asked about products marketed as refrigerators that use technology other than vapor compression. Based on the results of these surveys, DOE estimated that the household saturation of non-compressor refrigerators was only 2.1 percent (alternative refrigeration systems are discussed in section 0). DOE also estimated that approximately 400,000 absorption coolers are used in hotels, based on material provided by Dometic (Docket EERE-2011-BT-DET-0072, No. 7 at pp. 40, 42). Combining these data sources, DOE estimated that the overall household saturation of coolers in 2016 was 13.3 percent.

3.3 TECHNOLOGY ASSESSMENT

This section provides a technology assessment for MREFs. Contained in this technology assessment are details about product operations and configurations (section 3.3.1), typical controls and components (section 3.3.2), an examination of possible technological improvements for each product (section 3.3.3), and a characterization of the product efficiencies currently available (section 3.3.4).

3.3.1 Product Operation and Configurations

This section provides a brief description of the operation and configurations of MREFs.

3.3.1.1 Product Operation

MREFs are designed to operate in a manner similar to refrigerators, refrigerator-freezers, and freezers and are typically household appliances capable of refrigerated storage of beverages, food products, and other consumables (*e.g.*, beauty products or cigars). These products maintain compartment temperatures below the ambient temperature but typically higher than temperatures maintained in refrigerators, refrigerator-freezers, and freezers. Definitions for these product types and their operating temperature ranges are discussed in section 3.1.1.

A typical MREF consists of a refrigeration system intended to cool the contents of an insulated cabinet. The majority of MREF models available in the U.S. market use vapor-compression refrigeration systems. DOE is aware of coolers which alternatively rely on thermoelectric cooling. Historically, absorption-based coolers have also been sold in the U.S. market (see the October 2016 Direct Final Rule TSD). For combination cooler refrigeration products, DOE is only aware of products incorporating vapor-compression refrigeration systems. The following sections describe each of the three refrigeration technologies.

Vapor-Compression Refrigeration

Figure 3.3.1 shows a schematic representation of a typical refrigeration circuit used in consumer refrigeration products. As described by the American Society of Heating, Refrigerating and Air-Conditioning Engineers ("ASHRAE") *Refrigeration Handbook*,[21] the refrigeration process consists of the following steps:

1. Electrical energy is supplied to a motor that drives a compressor, which draws cold, low-pressure refrigerant vapor for the evaporator and compresses it.
2. The resulting high-pressure, high-temperature discharge gas then passes through the condenser, where it is cooled to saturation condition, condensed to a liquid, and possibly subcooled while heat is rejected to the ambient air.
3. Liquid refrigerant passes through a metering (pressure-reducing) capillary tube to the evaporator, which is at low pressure.
4. The low-pressure, low-temperature liquid in the evaporator absorbs heat from its surroundings, evaporating to a gas, which is again withdrawn by the compressor.

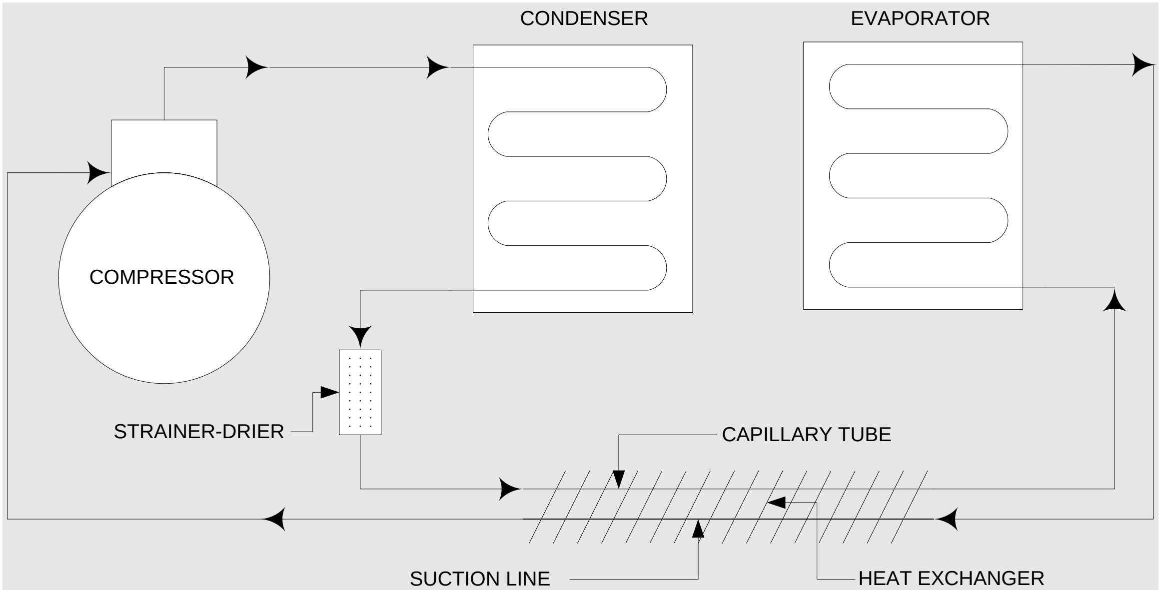

Figure 3.3.1 Refrigeration Circuit

In Figure 3.3.1, the metering or flow control device pictured is a non-adiabatic capillary tube. Non-adiabatic capillary tubes are the most common type of metering device in refrigeration products, as discussed in section 3.3.2.5.

Thermoelectric Refrigeration

Thermoelectric refrigeration systems operate using solid-state thermoelectric cooling modules, which are powered by direct current (DC) electric input. These modules function due to the Peltier Effect, which is the temperature differential created across the device when a voltage is placed across it. This creates a cold side, which cools the cabinet air inside a refrigeration product, and a hot side, which rejects heat to the ambient air around the product.

Absorption Refrigeration

Absorption-based refrigeration products work by using a heat source, powered by either electricity or fuel (*e.g.*, natural gas or propane), to provide the energy needed to drive the cooling system. Absorption refrigeration products use the ammonia-water absorption cycle to cool the cabinet. DOE could not identify examples of this technology currently in use in products certified as MREFs.

3.3.1.2 Product Configurations

Coolers

A typical cooler—in this example, a freestanding compact cooler for wine storage—is depicted in Figure 3.3.2. Because the most common primary function of a cooler is to store beverages (and potentially non-perishable foods), these products feature either shelves (*e.g.*, in beverage centers) or bottle racks (*e.g.*, in wine chillers). Coolers are similar in appearance to refrigerators, although coolers are typically sold with a glass door, rather than the solid, insulated doors found on refrigerators. This feature highlights the secondary function of coolers, which is to display the products (*e.g.*, bottles of wine) stored within.

Figure 3.3.2 Typical Freestanding Compact Cooler

Coolers range in size from countertop units that can store only a few small items to large cabinets capable of storing more than 100 bottles of wine. Some coolers feature dual or triple temperature zones, each of which may be independently controlled and some of which have their own external doors. This feature allows users to create separate storage conditions tailored specifically to different types of products; for example, a zone used to store white wine could be set at a lower temperature than a zone used to store red wine. Other units do not feature distinct temperature zones, but rather use natural temperature stratification within the cabinet to create "zones" that are not actually separated by any physical barrier or boundary.

Combination Cooler Refrigeration Products

Combination cooler refrigeration products combine the perishable food storage functionality of a refrigerator, refrigerator-freezer, or freezer with the beverage or non-perishable food storage functionality of a cooler. They consist of two or more compartments, of which at least one is a cooler compartment. Often, the temperatures in these compartments are controlled independently, as the freezer, fresh food compartments, or both must be maintained at lower temperatures than the cooler compartments. These compartments may be configured side-by-side or in an over-under arrangement. Figure 3.3.3 depicts an LG Signature cooler-freezer with upper cooler compartment and lower freezer drawers (*left*)[22] and a Zephyr side-by-side cooler-all-refrigerator (*right*)[23].

Doors for combination cooler refrigeration products are most commonly glass, enabling display of the contents, such as the cooler-all-refrigerator depicted in Figure 3.3.3. In some products, such as the cooler-freezer depicted in Figure 3.3.3, a glass door is used for the cooler compartment and a solid door is used for the fresh food or freezer compartment(s). Note that the temperature capabilities of each compartment determine a product's classification as a combination cooler refrigeration product rather than the presence of glass doors.

Figure 3.3.3 Combination Cooler Refrigeration Product Examples

3.3.2 Product Controls and Components

This section provides a brief description of the controls and components of the different types of MREFs. These descriptions provide a basis for understanding the technologies used to improve product efficiency.

The illustration in Figure 3.3.4 shows the components and layout of a typical vapor-compression refrigerator-freezer. The components and layout are similar in combination cooler refrigeration products and coolers, though most coolers typically have only one compartment. The text that follows describes the controls or components that are common to most refrigeration products, regardless of their cooling system: automatic defrost, temperature control, lighting, and door seals. A discussion of the components specific to each type of refrigeration system follows the general components for most refrigeration products.

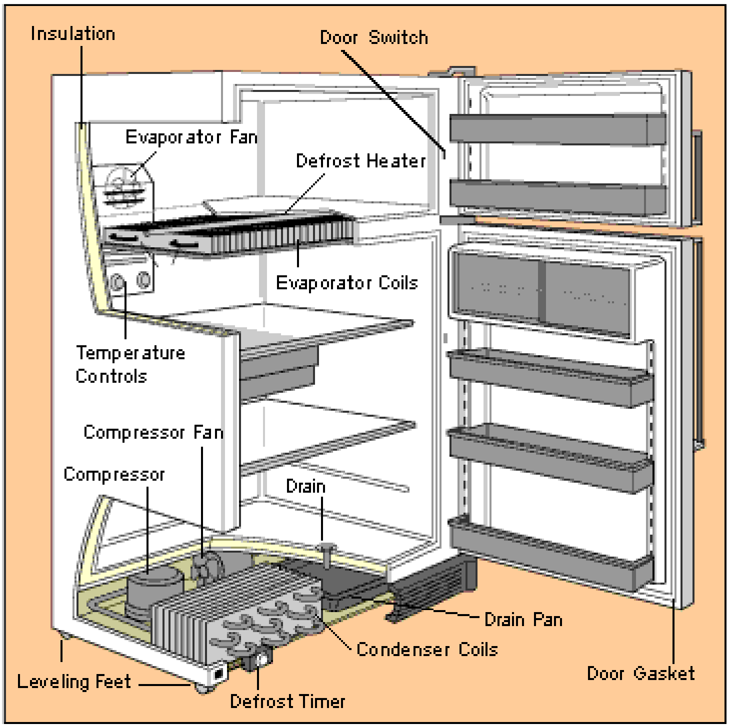

Figure 3.3.4 Components of a Vapor-Compression Refrigerator-Freezer[24]

3.3.2.1 Automatic defrost

Based on DOE's review of the market, the majority of MREFs are self-defrosting. Self-defrosting refrigeration products automatically melt frost that accumulates in the cabinet and on the evaporator. Automatic defrost may be passive or it may use an active control sequence.Passive defrost units defrost during compressor off-cycles, when the refrigerant in the evaporator is allowed to warm. Passive off-cycle defrost is commonly observed in coolers because of the warm compartment temperature typical for these products. Active defrost units use a heater to warm the evaporator to melt frost. The defrost control sequence is generally initiated after a prescribed number of compressor running hours. The typical mechanically-controlled active defrost system has three functional components: a defrost timer, a defrost heater, and a defrost thermostat.

- *Defrost timer:* The timer is a clock that is energized with the compressor. The timer initiates defrost after a set interval of compressor operation.

- *Defrost heater:* The defrost heater is an electric resistance heating element that melts any ice or frost that builds up. A heater may also be energized in the drip pan to prevent freezing of any melted condensate and clogging of the drip pan drain.

- *Drip pan:* As the frost and ice melt, the resulting water drips into a drip pan. The pan is connected to a tube that drains the water into a shallow pan underneath the insulated cabinet floor at the bottom of the MREF. The water is then evaporated by air which is drawn by a fan through the condenser and over the compressor shell. In some products which do not use forced convection condensers, a special pan is mounted on top of the compressor shell and the water is evaporated using heat from the compressor.

- *Defrost thermostat:* The process ends when the defrost thermostat mounted on the evaporator tubing senses that a sufficiently high temperature has been attained.

3.3.2.2 Temperature control

Most refrigeration products have a thermostat or electronic temperature control to maintain the proper temperature within the cabinet. Thermostats are mechanical devices that interrupt the electricity connection to the compressor when the cabinet temperature is sufficiently low. Electronic control systems generally use thermistors as temperature sensors, using relays mounted on the circuit boards to activate the compressor and other components such as the evaporator and condenser fans. Based on DOE’s engineering analysis and market review, electronic control systems with digital displays are the most common.

3.3.2.3 Lighting

Refrigerators, refrigerator-freezers, and freezers with internal lighting normally have only one functional lighting component, the switch, which is usually a white push-button mounted to be depressed by operation of the door. Closing the door turns off the light. Based on DOE’s review of MREF product literature, MREFs are frequently intended to display their contents even when the door (which is typically made of glass) is closed, and hence user-operable lighting switches are commonly found inside or outside the cabinet. In the October 2016 Direct Final Rule TSD DOE noted that refrigeration products traditionally used standard appliance incandescent light bulbs, but many new designs are using LED lighting. At present, LED lighting has achieved a high degree of market saturation, with most MREFs currently in the U.S. market utilizing this technology. Some MREFs allow the user to customize the display color of the cabinet with programmable, multi-color LED lighting. While display and lighting are a key difference between MREFs and other refrigeration products, lighting is typically not active for testing MREFs according to the DOE test procedure.

As discussed in section 3.2.1.2, DOE is aware of novel refrigeration products designed and marketed to allow users to grow produce (such as herbs and microgreens) at home. For these products, the cabinet lighting is necessary for the normal operation as it provides for ideal growing conditions. Accordingly, DOE may consider the energy consumption of lighting for such products in a future test procedure or analysis of potential energy conservation standards for produce growers.

3.3.2.4 Door Seals

All MREFs have a seal—a vinyl gasket attached to the door(s). The seal prevents infiltration of warm ambient air into the cabinet. The seal is lined with a magnet which helps to hold the door closed and create a tight seal. The magnetic portion of the gasket is aligned to face the steel extension of the cabinet’s external shell which wraps partially around the front face of the cabinet. Some gasket systems use opposing magnets on the cabinet side to improve door sealing force.

3.3.2.5 Vapor-Compression Cooling

The following sections describe each of the main components found in a vapor-compression refrigeration product.

- *Compressor:* The compressor increases the pressure of the refrigerant, providing the energy input necessary to drive the refrigeration cycle. In most refrigeration products, the compressor is located at the bottom rear of the unit. The compressor runs whenever the thermostat calls for cooling.

- *Condenser:* The condenser is a heat exchanger located on the outside of the refrigerated compartment. The three most prevalent condenser configurations are as follows:
    - Forced-convection condensers use fans to move air through them to provide cooling. These condensers are usually located under the unit, near the compressor.They can be fabricated of steel tubes with steel wire fins or copper or aluminum tubes with aluminum fins.
    - Natural convection "static" condensers, which do not use fans, are mounted to the back of the unit. They generally have steel tubes and steel wire fins.
    - Hot wall condensers are integrated into the outer shell of the unit. A serpentine of tubing is attached to the inside of the shell and provided with good thermal contact to the shell. This is a common configuration in compact coolers.

- *Metering or Flow Control Device (Capillary Tube):* The metering device in most vapor-compression consumer refrigeration products is a capillary tube. There are two common types of capillary tubes: adiabatic and non-adiabatic. Non-adiabatic capillary tubes, which are the most common, are soldered to the suction line to evaporate the residual liquid and warm the vapor, thereby increasing the refrigeration capacity of the system. Adiabatic capillary tubes do not exchange heat with the suction line and therefore allow the refrigerant to expand adiabatically (*i.e.*, without heat transfer). The capillary tube controls the pressure and flow of the refrigerant as it enters the evaporator.

- *Evaporator:* The evaporator is a heat exchanger located inside the unit. There are three main configurations for evaporators:
    - Forced-convection evaporators use fans to move air through them to provide cooling. They are constructed of aluminum tubes and aluminum fins or copper tubes and aluminum fins. They are generally located on the rear wall of the compartment behind a panel. They can also be located in the mullion separating compartments, as shown in Figure 3.3.4. The evaporator fan circulates air through the evaporator and into the compartments. Because the evaporator absorbs heat, it is very cold, thereby causing any water vapor in the air to freeze on it as frost.Many refrigeration products using this type of evaporator employ automatic defrost.
    - Roll-bond evaporators are fabricated from layers of aluminum sheet and primarily use natural convection cooling. The refrigerant passages are formed into the evaporator walls. They are common in coolers and are configured as a flat plate at the rear of the cabinet. While these evaporators generally use natural convection and do not use an evaporator fan, some products with rear-mounted flat roll-bond evaporators use fans for performance enhancement.

- Coldwall evaporators are integrated within the walls of the cabinet. This configuration is used in some compact coolers. The evaporator consists of tube serpentines attached to the insulation side of the cabinet interior liner. These evaporators use natural convection heat transfer.

3.3.2.6 Thermoelectric Cooling

Besides the thermoelectric modules themselves, which can be connected in series to increase cooling capacity, thermoelectric refrigeration products typically employ aluminum heat sinks on one or both sides of the module in order to maximize heat transfer. Most refrigeration products that utilize thermoelectric cooling also employ small, DC-powered fans, similar to the fans used to cool computers, to improve heat transfer across the heat sinks. Some units have a "condensing" heat pipe on the rear of the unit. Such heat pipes are filled with refrigerant that carries the heat away from the hot side of the module, reducing the need for fans or heat sinks to improve heat transfer.

3.3.3 Technology Options

Table 3.3.1 lists the technology options available for MREFs. The technology options are categorized by their associated component or system. Each technology option category and the options available for improving the component or system category are discussed below.

Table 3.3.1 Technology Options for MREFs

Insulation	**Condenser**
Improved resistivity of insulation (insulation type)	Increased surface area
Increased insulation thickness	Tube and Fin Enhancements (including microchannel designs)
Vacuum-insulated panels	Forced-convection condenser
Gas-filled insulation panels	**Defrost System**
Gaskets and Anti-Sweat Heat	Off-cycle defrost
Improved gaskets	Reduced energy for active defrost
Double door gaskets	Adaptive defrost
Anti-sweat heat	Condenser hot gas defrost
Doors	**Control System**
Low-E coatings	Electronic Temperature control
Inert gas fill	Air-distribution control
Vacuum-insulated glass	**Other Technologies**
Additional Panes	Fan and fan motor improvements
Frame design	Improved expansion valve
Solid door	Fluid control or solenoid off-cycle valve
Compressor	Alternative refrigerants
Improved compressor efficiency	Improved refrigerant piping
Variable-speed compressors	Component location
Linear compressors	Alternative refrigeration systems
Evaporator	
Increased surface area	
Forced-convection evaporator	
Tube and Fin Enhancements (including microchannel designs)	
Multiple evaporators	

3.3.3.1 Insulation

The primary thermal load on an MREF is typically the heat transfer through the walls and doors into the cabinet. Nearly all MREFs use polyurethane (“PU”) foam insulation for the cabinet walls and any solid doors. Through the 1980s, CFC-11, a chlorofluorocarbon (“CFC”), was used as a blowing agent in almost all PU foam insulation. However, under the Montreal Protocol, all CFCs were banned from use by the mid 1990s due to their high ozone depletion potential (“ODP”).

In the 1990s, most manufacturers adopted use of HCFC-141b, a hydrochlorofluorocarbon (“HCFC”), which has significantly less ODP. However, because HCFC-141b has non-zero ODP, it was banned from production in the U.S. after January 1, 2003.

In response to the phase-out of HCFC-141b, AHAM’s Appliance Research Consortium (“ARC”) investigated several alternatives, including two hydrofluorocarbons (“HFCs”), HFC-134a and HFC-245fa, and cyclopentane, a hydrocarbon (“HC”). HFCs and HCs both have zero ODP. HCs have a much lower global warming potential (“GWP”) than HFCs, but they are flammable. ARC, DOE, and EPA sponsored research at Oak Ridge National Laboratory (“ORNL”) to determine the thermal conductivities of the three alternatives and of HCFC-141b.

Based on thermal conductivity, ORNL identified HFC-245fa as the most attractive substance because it had the lowest energy penalty relative to HCFC-141b (see Table 3.3.2).[25] In addition, accelerated lifetime performance tests conducted by ORNL indicated that the thermal conductivity of HFC-245fa foam insulation increases by a smaller percentage than either HFC-134a or cyclopentane foams. Finally, despite the fact that HCs are used in Europe, flammability and volatile organic compound concerns led ARC to determine that HFCs were a more suitable replacement blowing agent.[26] As a result, many manufacturers switched to HFC-245fa blowing agent for PU foam insulation.

Table 3.3.2 Thermal Conductivity of Freshly-Sliced Foam Specimens at 75 ºF (23.9 ºC)

Blowing Agent	**Slice Thickness**			
	0.4 inch (1.0 cm)		**1.5 in (3.8 cm)**	
	Btu-in/hr-ft²-ºF	*mW/m-K*	*Btu-in/hr-ft²-ºF*	*mW/m-K*
HCFC-141b	0.132	19.0	0.128	18.4
HFC-245fa	0.138	19.9	0.132	19.0
Cyclopentane	0.150	21.6	0.145	20.9
HFC-134a	0.160	23.1	0.155	22.3

Source: ORNL, 2003.[25]

Improved Resistivity of Insulation

Past research has investigated improving the resistivity of PU foam insulation through the use of additives in the foam.

Research conducted in 1996 demonstrated that adding carbon black provides a means of improving the thermal insulation properties of PU foam. The research showed that PU foam systems using carbon black in conjunction with either HCFC-141b or cyclopentane was able to lower *k*-factors by six to nine percent in panels and in cabinets.[27]

More recently, manufactures have introduced new hydrofluoro-olefin ("HFO") low-GWP blowing agents with claims of improved efficiencies and thermal resistivities from 2 percent to 11 percent compared to the existing HFC-245fa blowing agents.[28,29] A number of manufacturers have already incorporated these higher efficiency blowing agents into refrigeration products currently available on the market.[30,31]

CO_2 is another blowing agent under investigation for use in refrigeration products. Similar to other alternative blowing agents, the goal of using CO_2 as a blowing agent is to improve the thermal performance of insulating PU foam. Additionally, CO_2 is non-flammable and has a lower GWP than other alternatives. One major limitation of using CO_2 as a blowing agent is the density of the resulting PU foam, which is almost two times that of typical PU foam (61 kg/m^3 vs. 33 kg/m^3).[32] DOE is not aware of CO_2 used as a blowing agent for any commercially available MREFs.

Increased Insulation Thickness

Current MREF designs typically include 1 to 2 inches of insulation in their walls. Increased insulation thicknesses around the refrigerated compartment reduces heat transfer into the cabinet and reduces the heat load on the refrigeration system, improving MREF efficiency. However, such desigh changes would require significant investments in foaming systems, tooling, and molding to accommodate thicker insulation. Increased packaging and shipping costs must also be considered. Greater insulation thickness typically results in either decreased interior volumes, increased exterior dimensions, or some combination of both. Because kitchen dimensions and designed spaces for MREFs are limited, there are restrictions on increasing the exterior size of the product. Reducing interior volume is considered undesirable because it impacts consumer utility.

Vacuum-Insulated Panels

Vacuum-insulated panel ("VIPs") technology is based on the reduction in conductivity which occurs in a low vacuum. VIPs used in refrigeration products consist of a sealed package with a fill material which provides support to prevent the panel from collapsing and interferes with molecular mean free path as the intermolecular spacing increases at lower vacuum levels. VIPs can be foamed in place between the cabinet liner and wrapper to decrease the heat leakage and energy required to maintain the cabinet at low temperature. Different configurations are commercially available through advances in manufacturing technologies. Typical VIPs generally consist of a core material and an airtight envelope. Some VIPs also include absorber to absorb gas that leaks through the envelope.

Several core materials have been used in the manufacture of VIPs including polystyrene, open-cell PU, silica powder, and glass fiber. Research sponsored by the European Commission has evaluated these core materials based on their cost and characteristics, including density and manufacturing time. Table 3.3.3 below summarizes the VIP characteristics manufactured with the above core materials.[33] Each of the core materials has associated advantages and disadvantages that dictate their acceptability for an appliance application.

Table 3.3.3 Comparison of Various VIP Core Materials

Property		**Polystyrene**	**Open-cell PU**	**Silica Powder**	**Glass Fiber**
Thermal Conductivity at 10 Pascals (Pa) abs. (0.1 millibar (mbar))	(*mW/m-K*)	4.8 – 5.8	9.7	5.8	2.4
	(*Btu-in/hr-ft^2-°F*)	0.033 – 0.040	0.067	0.040	0.017
Manufacturing Time		Fast	Medium	Medium	Long
Density (*kilogram*(*kg*)*/cubic meter* (*m^3*))		80 – 144	64	192	128
Drying Need		No	Yes	Yes	No
Thermal Stability		Low	Medium	Good	Very Good
Recyclability		Yes	Difficult	Yes	NA
Cost		Low	Medium	High	Very High

Source: European Commission, 2000.[33]

ORNL also has evaluated the performance of three types of VIPs: a silica powder filler encapsulated in a polymer barrier film; a fibrous glass insulation filler encapsulated in a stainless steel barrier; and an undisclosed insulation filler encapsulated in a stainless steel barrier.[34] Table 3.3.4 summarizes the center-of-panel thermal conductivities of the panels. For the silica powder and glass fiber filled VIPs, the thermal conductivities in Table 3.3.4 are comparable to those in Table 3.3.3.

Table 3.3.4 Center-of-Panel Thermal Conductivity of VIPs

Property		Silica Powder	Glass Fiber	Unknown
Thermal Conductivity*	*(mW/m-K)*	5.2 – 5.4	2.0 – 2.6	2.7 – 3.1
	(Btu-in/hr-ft²-ºF)	0.034 – 0.038	0.014 – 0.018	0.019 – 0.022

***** For each filler, the reported thermal conductivities are a range of values from nine separate VIPs.

Source**:** Vineyard et al, 1998.[34]

Of significant concern for VIPs is their long-term thermal conductivity integrity. VIP thermal conductivity increases dramatically as the pressure within the VIP exceeds 100 Pa abs. (1 mbar). The pressure increase in the VIP over time is related to several factors, including: residual gases in the VIP after vacuum, degassing from the VIP core material, and gas diffusion through the envelope pores. Improved envelopes and absorbers have been developed to prevent pressure increases from occurring in VIPs. A study published in 2013 found that service life of VIPs can exceed 15 years if desiccants are integrated into core materials.[35] More recently, a study published in 2014 recommends using large square VIPs with thickness of 1.0-2.5 cm. Furthermore, service life of 10-15 years or above 20 years can be achieved by adding different absorbents for different application fields.[36]

Matsushita's VIP technology (trade name of "U-Vacua") was awarded the Minister of Economy, Trade and Industry Prize at the 17th Energy Conservation Awards sponsored by the Energy Conservation Center of Japan in January, 2007.[37] Matsushita claimed that its VIP technology has achieved the world's highest level of insulation efficiency with a thermal conductivity of 1.2 mW/m-K (0.008 Btu-in/hr-ft^2-ºF) at 24 ºC (75.2 ºF).[38] Va-Q-tek has also introduced its va-Q-plus VIP technology.[39]

Much research has been done in the area of VIP technology. In a study published in 2012, the Chinese Vacuum Society reported that VIPs can reduce refrigerator energy consumption by 25% without an effective volume decrease.[40] Research has also been done on the material used in VIPs. In a study published in 2015, VIPs with super-stratified glass fiber core material were prepared by centrifugal-spinneret-blow ("CSB") process. The results of the study show that the VIPs with this material were up to two times more thermally insulating than conventional wet core material. Additionally, the CSB material performed better than conventional wet process material under various pressures.[41]

DOE notes that the innovations in 3D VIPs, which can fold to fit the contours of a refrigerator cabinet design, may help to reduce edge leakage losses in MREFs. Va-Q-Tec manufactures VIPs in 3D shapes, folded VIPs, panels with cut-outs, shaped corners or apertures, and cylindrical or round panels for refrigeration applications.[h] Although, DOE is not aware of MREF products in the United States using these novel technologies.

Gas-Filled Panels

Gas-filled panels ("GFPs") use thin polymer films and low-conductivity gas to create a device with excellent thermal insulation properties. GFPs are essentially hermetic plastic bags that can take on a variety of shapes and sizes. Inside the outer barrier is a cellular structure called a baffle which is filled with the low-conductivity gas.

[h] Product literature is available at va-q-tec.com/en/technology/vacuum-insulation-panels/materials-shapes/. (Joint Advocates, Document No. EERE-2017-BT-STD-0003-0012, p. 2)

In response to the December 2020 Early Assessment RFI, NEEA stated that multi-chamber gas-filled panels with aluminum foil partitions can be applied to MREF products, and by layering the gas-filled panels with aluminum foil sheets, insulation can be improved at a relatively low cost.[i] (NEEA, No. 7 at p. 3)

Research conducted at LBNL in the mid-1990s has demonstrated the effectiveness of GFPs based on the use of different gases, including xenon and krypton. Table 3.3.5 below summarizes the thermal performance characteristics of different GFPs, based on their center-of-panel and whole-panel performance.[42] LBNL has also conducted research to demonstrate that GFPs, when used in refrigerator-freezers, can reduce energy consumption by approximately eight percent relative to PU foam insulation.[43]

Table 3.3.5 Comparison of Various Gas-Filled Panel Core Materials

Gas Fill	Center of Panel Performance		Whole Panel Performance					
	Thermal Conductivity		Panel Thickness		Mean Temp.		Thermal Conductivity	
	mW/m-K	*Btu-in/hr-ft²-°F*	*mm*	*inches*	*°C*	*°F*	*mW/m-K*	*Btu-in/hr-ft²-°F*
Xenon	7.4	0.051	24.1	0.95	6.8	44.2	7.4	0.051
Krypton	11.6	0.080	25.2	0.99	11.9	53.4	10.77	0.074
			49.8	1.96	12.3	54.1	1.17	0.008
Argon	19.9	0.138	NA	NA	NA	NA	NA	NA
Air	28.1	0.195	NA	NA	NA	NA	NA	NA

Source: LBNL[42]

In addition, ORNL determined the thermal conductivity of an insulation panel containing radiation baffles within a polymer barrier film and filled with krypton gas at atmospheric pressure. The range of thermal conductivities of nine of these GFPs ranged from 0.088 to 0.092 Btu-in/hr-ft^2-ºF (12.6 to 13.2 mW/m-K). ORNL also analyzed the GFPs as part of a composite assembly consisting of a one-inch panel surrounded by PU foam insulation to form a two-inch-thick panel. The average composite panel thermal resistance was determined to be 18.2 hr-ft^2-ºF/Btu. Finally, ORNL measured only a five-percent reduction in overall thermal resistance over a three-year period, which was less than the reduction observed in a panel consisting only of PU foam insulation.[34]

The 2011 study cited by NEEA similarly indicated that GFPs range from 0.010 to 0.020 W/m-K in thermal conductivity. Additionally, as NEEA indicated, Kralj *et. al.* investigate GFP designs with aluminum barriers as opposed to polymer films.[44] However, DOE notes that the design proposed by Kralj *et. al.* may pose significant challenges to MREF cabinet construction because the novel design is rigid and approximately 1.75 inches thick.

Although research has demonstrated that GFPs have better thermal performance than PU foam insulation, DOE is not aware of any MREFs using the technology. DOE expects that

[i] NEEA cited a 2011 study by Kralj *et. al.* titled "Gas-filled panels as a high insulation alternative for 21st century building envelopes," available at: www.researchgate.net/publication/286452690_Gas-filled_panels_as_a_high_insulation_alternative_for_21_st_century_building_envelopes

manufacturers would likely incorporate VIPs rather than GFPs because both insulation types introduce similar issues, while VIPs offer better insulating characteristics.

3.3.3.2 Gaskets and Anti-Sweat Heat

A significant portion of the heat gain to consumer refrigeration products occurs around the edges of the doors and through the gaskets on the door edges. For example, an analysis of thermal loads on an 18.6 ft^3 top-mount refrigerator-freezer revealed that over 28 percent of the total heat load into the cabinet came from "edge" loads, *i.e.*, loads due to heat transfer into the food compartments via paths around the perimeter of the cabinet aperture.[45] If the "edge" effect losses can be reduced, the efficiency of the refrigeration product can be increased. Gaskets and anti-sweat heat contribute to these "edge" effects.

Improved Gaskets

Design of door gaskets is a balance between improving the thermal-efficiency performance of the gasket and ensuring that the door is not difficult to open. If the gasket magnet force is too strong, it becomes difficult to open the door. Based on a European Commission study, door handles have been designed specifically to facilitate door openings by providing leverage and relieving the pressure differential which can build up by freeing a small section of the gasket before the door is opened.[33] Although materials and designs for improving the air tightness of door gaskets exist, apparently no general criteria have been established to enable different designs to be classified.

In 2011, a study was published where temperature measurement and numerical heat transfer analysis were conducted and compared to each other to achieve a more proper numerical analysis method. The study found that heat loss through the magnetic door gasket can potentially reach 30 percent of total thermal heat loss of a refrigerator. The reason for the relatively high amount of heat loss near the door gasket was due to the thinness of the insulation of the door gasket and the existence of anti-sweat heat to prevent dew formation near or on the door.[46] Anti-sweat heat is discussed separately below.

The thermal loads on gaskets in coolers is less pronounced compared to other consumer refrigeration products that maintain lower compartment temperatures. However, combination cooler refrigeration products do consist of at least one compartment maintaining these lower temperatures; as such, improved gaskets may provide more efficiency gains for combination cooler refrigeration products than for coolers.

Double Door Gaskets

A double door gasket is an additional inner door seal gasket that is added to the gasket design. This further reduces heat leakage and infiltration into the refrigeration product. However, these gaskets can result in ice build-up, which reduces effectiveness, and can increase the difficulty of meeting safety regulations for minimum door-opening force.

Anti-Sweat Heat

Anti-sweat heaters are commonly used in refrigerator-freezers but are not found in all MREFs. These heaters apply heat to external surfaces near door gaskets, possibly including the mullion region between compartments, and along the perimeter of the cabinet. If electric resistance heaters are used for this purpose, the heaters contribute to energy consumption both with their wattage input and with the heat load they generate that enters the cabinet, and improved controls or appropriate heater sizing may allow for reduced energy consumption.

In response to the December 2020 Early Assessment RFI, NEEA indicated that refrigerant anti-sweat heat can reduce energy consumption compared to electric anti-sweat heaters. (NEEA, No. 7 at p. 3) Several MREF designs use refrigerant tubes inserted in the cabinets in proximity to the regions requiring heat. Either hot discharge refrigerant gas from the compressor or warm liquid refrigerant leaving the condenser may be used to provide this heat, although warm liquid refrigerant is more common. This effectively allows the anti-sweat heat pipe to extend the condenser surface area and improve subcooling.

NEEA also commented that rerouting waste warm air is another option that can reduce energy use of anti-sweat heat systems. (NEEA, No. 7 at p. 3) DOE is not aware of any commercially available MREFs which utilize this approach.

The heat loads from both electric and refrigerant type anti-sweat heaters can be significant when this feature is active. For many MREFs (especially coolers), compartment temperatures are not maintained low enough to initiate the formation of condensate near the door and gasket, hence anti-sweat heat may not always be necessary during normal operation, and improvements to anti-sweat heat may have limited impact.

3.3.3.3 Doors

Unlike refrigerators, refrigerator-freezers, and freezers, which typically enclose their refrigerated compartments with solid insulated doors, coolers most frequently utilize double-paned glass doors, which enable the cooler to act as both a refrigerated compartment and a display case. However, the thermal resistance of glass doors can be up to three times lower than the thermal resistance of traditional solid, insulated refrigerator doors; therefore, door losses can account for a substantial portion of the thermal load in a cooler.

The thermal resistance of glass doors can be improved by making improvements to the glass pack such as adding a low-emissivity coating, an inert gas (*e.g.*, argon or krypton) filling, or a third pane of glass. Such design changes could significantly increase the door’s overall thermal resistance, thus reducing conductive and radiative heat transfer through the door.

Low-Emissivity (“Low-E”) Coatings

Low-E coatings on glass panes used in MREF glass doors improve efficiency by reducing the rate of radiative heat transfer through the door. Emissivity is a measure of a surface’s ability to emit thermal radiation, and surfaces with low emissivity values reduce the thermal load on the refrigerated cabinet by reducing the amount of thermal radiation which penetrates the cabinet through the glass doors. Low-E coatings are distinct from glass tints, which may be applied to MREF glass doors to block the penetration of ultraviolet radiation and visible light.

Transparent, low-E coatings reflect invisible far infrared wavelengths while still allowing visible light to pass through. There are two types of low-E coatings used for glass: “soft-coat” and "hard-coat." Soft-coated glass is manufactured using sputtering and typically results in lower emissivities and thermal conductivities than hard-coated glass. Soft-coated glass is less durable than hard-coated glass, and the coated side is typically the inner face of a glass pack to avoid exposure to ambient moisture. Hard-coated glass is manufactured using chemical vapor deposition and a pyrolytic application to hot, unfinished glass.[47] The material which is coated onto the glass in both soft-coat and hard-coat applications is typically metallic silver.[48]

Many MREFs are marketed to have low-E coated glass doors; however, the precise emissivity value or application type is usually not specified. DOE expects that manufacturers may opt to improve the efficiency of MREFs by utilizing soft-coated glass as opposed to hard-coated glass. Additionally, multiple soft-coat layers may be applied to substantially lower the emissivity—up to the point where the glass is effectively a mirror.

Inert Gas Fill

Similar to GFPs (discussed in section 3.3.3.1), inert gases may be used in glass packs to reduce thermal conductivity of glass doors. In the previous rulemaking, DOE considered three options for the gas fill between glass panes in MREF glass doors: air, argon, and krypton (in order of increasing thermal resistance). (*See* Tables 5.12 and 5.17 in the October 2016 Direct Final Rule TSD). DOE found that many MREFs today are marketed with argon as the insulating gas. DOE did not find any product literature indicating instances of krypton being used in MREFs.

Vacuum-Insulated Glass Packs ("VIGs")

Glass packs for display doors can also be designed with a vacuum between the panes. Similar to VIPs (also discussed in section 3.3.3.1), this lends to substantial improvements in energy efficiency. Product literature for VIGs used in walk-in cooler display doors indicates that the spacing between glass panes is dramatically reduced when a vacuum is used. Anthony International VIGs have a total pane-to-pane thickness of only 0.38 inches, with just 0.22 mm of vacuum separating the panes. This manufacturer's product literature also indicates that VIGs provide increased visibility of the interior space.[49] While DOE may consider VIGs for larger refrigeration equipment[j], DOE did not find any product literature indicating instances of VIGs being used in MREFs.

Additional Panes

Glass packs for doors used in refrigeration products are usually comprised of two or three glass panes. The addition of a third pane allows for additional layer of low-E coated glass and inert gas to be present, thereby improving the overall resistivity of the glass door. One tradeoff for installing an additional pane would be the increased weight of the glass pack, which may be a substantial consideration for standard-sized MREFs.

Frame Design

Frame designs mitigate "edge" effects similar to insulating gaskets. Glass door frames are typically made using a combination of aluminum and PVC—the aluminum providing structural support, and the PVC providing thermal insulation. Additionally, MREF door frames may be

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[j] DOE requested information regarding VIGs in an RFI for walk-in coolers and freezers. 86 FR 37687, 37695 (July 16. 2021).

constructed with air gaps to act as thermal breakers. The precise form of the frame materials can have a significant impact on the frame's overall thermal conductivity. In response to a request for information regarding walk-in coolers and freezers (which may also use glass display doors), Anthony International, a manufacturer of glass doors, indicated that the thermal conductivity of the frame is always higher than that of the glass pack. (Anthony International, EERE-2017-BT-STD-0009-0015, p. 1) DOE expects that manufacturers may improve the three-dimensional design of glass door frames in order to improve the efficiency of an MREF.

Solid Door

Alternatively, the typical glass door for an MREF can be replaced by a solid, insulated door, identical to the style of door used in refrigerators, refrigerator-freezers, and freezers. Although this would dramatically reduce heat loss through the door, as the resistivity of PU foam is significantly higher than the resistivity of most glass doors, it would also eliminate the cooler's function as a display case. Solid doors can often be found in MREFs on the fresh food or freezer compartments of combination cooler refrigeration products, as shown in Figure 3.3.3.

3.3.3.4 Compressor

The compressor is typically the primary energy-consuming component in a refrigeration product. Therefore, technologies that can advance compressor efficiency have a significant effect on overall product efficiency.

Refrigeration products use positive-displacement compressors in which the entire motor-compressor is hermetically sealed in the welded steel shell. Two types of compressors have historically been used in these refrigeration products—reciprocating and rotary. However, reciprocating compressors are now predominantly used in MREFs.

Almost all compressors are directly driven by two-pole squirrel-cage induction motors running at approximately 3,000 rpm on 60 Hz power. Three types of induction motors have been used in refrigerator compressors: resistance start/induction run ("RSIR"), capacitor start/induction run ("CSIR"), and resistance start/capacitor run ("RSCR"). Of the three motor types, the RSIR motor is the least efficient. As a result of the U.S. energy efficiency standards that took effect in 1993 and 2001, the vast majority of compressor motors transitioned to the RSCR type.

There are two broad categories of compressors used in refrigeration products: single-stage compressors, and variable-capacity compressors. Variable-capacity compressors, including variable-speed compressors and linear compressors, have the ability to modulate the amount of cooling capacity provided (and thus the amount of power input required) either by modulating the compression speed or the displacement volume.

MREF compressors are similar to those used in refrigerators and refrigerator-freezers and are typically rated at the same conditions. At low back pressure rating conditions ("LBP")[k],

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[k] Typically, these conditions are -10 ºF (-23.3 ºC) suction dew point (evaporating temperature) and 130 ºF (54.4 ºC) discharge dew point (condensing temperature) for positive displacement compressors used in refrigerating appliances.

cooler compressor capacities typically range from approximately 200 to 600 Btu/hr, although most cooler compressor capacities fall between 300 and 400 Btu/hr. The actual operating conditions for compressors in coolers under the established DOE energy test conditions can be significantly different than compressor rating conditions. Most notably, the evaporating temperatures are generally significantly higher than -10 ˚F. However, combination cooler refrigeration products operate at lower evaporating temperatures than coolers do. At higher evaporating temperatures, compressor capacities are substantially higher but thermal load on the cabinet is also substantially lower, so single-stage compressors used in MREFs are often oversized compared to actual cooling load. These compressors cycle on and off to avoid overcooling the cabinet.

Improved Compressor Efficiency

Conversion to high-efficiency single-stage compressors is a fairly straightforward design change for manufacturers to implement because it is only a component change. At LBP conditions, efficiencies for the single-stage compressor types that are utilized in the most common types of U.S. refrigeration products range from a minimum of approximately 3.0 Btu/Wh to a maximum of approximately 6.5 Btu/Wh. Single-stage R600a compressors specifically range from 4.5 Btu/Wh to 6.5 Btu/Wh. (See chapter 5 of this TSD) This indicates that manufacturers using inefficient compressors have an opportunity to significantly reduce energy consumption by upgrading compressors. However, compressor efficiency is also a function of refrigeration capacity. The reduced efficiency for lower-capacity compressors has been attributed to optimization of performance for higher-capacity compressors[50] and to the higher importance of mechanical losses and losses associated with re-expansion of gases left in the clearance volume as the swept volume of the reciprocating piston decreases. However, it is important to note that compressor efficiencies at higher back pressures (*i.e.*, higher evaporating temperatures) may not perfectly correlate to rated efficiencies at lower back pressures. See chapter 5 of this TSD for a description of the range of compressor efficiencies considered in this analysis.

Variable-Speed Compressors

Variable-speed compressors allow efficiency improvements over single-speed compressors because they can provide a better match of thermal loads during the vast majority of operating hours when the loads are low. The rated efficiencies of these variable-speed compressors are not necessarily higher than the best efficiencies of single-speed compressors. However, variable-speed compressors typically operate at low speed with a high percentage of on-time, resulting in lower energy consumption by reducing off-cycle losses and by allowing the heat exchangers to operate with lower mass flow, thus increasing their effectiveness. However, increased fan run times associated with greater compressor runtime offset a portion of the compressor energy savings.

Electronic controls are used to vary the speed of variable-speed compressors, which typically use inverter-driven induction motors. Most U.S. refrigeration products do not currently use variable-speed compressors, but the use of these compressors is becoming more common. DOE is aware of a number of refrigeration products currently on the market that use variable-speed compressors.

Various past studies have illustrated a range of energy savings achievable through use of variable speed compressors. Arthur D. Little reported savings of approximately 25 percent compared to single-speed motor systems in 1999.[51] Research conducted by Tecumseh Products Company demonstrated that energy savings of 15 percent as well as reduction of sound and vibration levels.[52] Simulation analyses conducted at the University of Illinois demonstrated that steady-energy savings ranging from four to 14 percent could be realized through the use of a two-speed compressor in concert with multiple-speed evaporator and condenser fans. The research also demonstrated that an additional 0.5 to four percent in energy consumption could be saved through the reduction of cycling frequency, *i.e.*, the number of starts.[53] More recently, researchers have estimated 15 percent energy savings and more stable compartment temperatures for refrigeration products using a variable-speed compressor compared to a conventional refrigeration system.[54]

Linear Compressors

Linear compressors employ a different design than either reciprocating or rotary compressors and are reportedly more efficient than either. These compressors use a linear rather than rotary motor, thus eliminating the crankshaft and linkage which converts the rotary motion to the linear motion of the piston of a reciprocating compressor. Elimination of the mechanical linkage reduces friction and side-forces. The linear motor requires power electronics and a controller to assure proper piston throw. Most linear compressor designs use a free piston arrangement and can be controlled for a range of capacities through adjustment of piston displacement. Early work on the concept suggested that the compressors can operate without requiring oil, which could provide additional energy benefit by improving heat transfer in the evaporator. Noise levels can also be reduced by utilizing linear compressors in the same way that this can be done with variable-speed compressors, by operating most of the time at low capacity.[55]

An early version of the linear compressor design was developed by Sunpower for integration into refrigerators for the European market using isobutane (R-600a) as a refrigerant.[56] LG has developed a linear compressor for refrigeration products which does not require use of oil. LG currently offers many products, including side-by-side and french door refrigerators, that use linear compressors.[57] LG claims that its line of linear compressors is up to 20 percent more efficient than reciprocating designs.[58]

In 2010, Embraco, a Brazilian compressor manufacturer, announced the development of a new oil-free linear compressor for household refrigerators in conjunction with the appliance manufacturer Fisher & Paykel. The Embraco Wisemotion linear compressor, which was to be launched to 3-4 OEM customers, is said to be half the size of LG's linear compressor to reduce materials and offer higher performance.[59] Embraco claims that this compressor is the world's first oil-free household compressor and is up to 40 percent more efficient than competing designs.[60]

3.3.3.5 Evaporator

The evaporator is a key component of the refrigeration system and is located within the cabinet or behind the cabinet's inner lining. There are three basic evaporator designs in coolers: a forced-convection finned-tube design; a roll-bond design; and a "coldwall" evaporator that is integrated within the shell of the unit. DOE expects that evaporator performance can be enhanced by increasing the heat exchanger surface area or improving the heat exchange performance.

Increased Surface Area

Increasing the heat exchanger surface area can be achieved by increasing the face area of the evaporator or adding more tube rows. These measures can be limited by the geometry of the cooler.; therefore, there may be a tradeoff between increasing the volume occupied by the heat exchanger and reducing the interior volume of the cooler. Increasing heat exchanger surface area allows for the same amount of heat transfer for a smaller temperature difference. As a result, larger heat exchanger areas allow for higher evaporator temperatures to accomplish the same cooling, leading to more efficient refrigeration system operation.

Forced-Convection Evaporator

Many compact coolers use coldwall or roll-bond evaporators, whereas most full-size coolers use forced-convection evaporators. The forced convection evaporator configuration can provide higher heat transfer effectiveness. However, space for housing a forced convection evaporator and its associated fan is not always available. The consideration of conversion to forced-convection evaporators will depend on whether a particular product is designed in a way that allows housing of the evaporator and fan in a suitable location.

Tube and Fin Enhancements

For forced-convection evaporators, improving heat exchanger performance can be achieved through the use of enhanced fins and/or tubes. These types of fin and tube enhancements are common in air-conditioning applications where slit and louvered designs are used to enhance the fin surface and different types of internally-grooved surfaces are used to enhance the tubing.

Another heat exchanger technology that could potentially improve evaporator performance is microchannel heat exchangers. Past research has demonstrated that the use of such heat exchangers in domestic refrigerators can provide system efficiencies comparable to current technologies while reducing refrigerant charge.[61]

Multiple Evaporator Systems

Refrigeration products can use multiple evaporators to provide cold air separately to individual compartments or sub-compartments. For these systems, refrigerant flows either to one evaporator at a time by operation of a control valve (*i.e.*, a "tandem" system) or to both evaporators in series (*i.e.*, a "sequential" system). Multiple evaporators can improve refrigeration system efficiency by providing some portion of the cooling load at a higher evaporator temperature. Additionally, multiple evaporators may be used for precise temperature control, which may be a desirable feature for coolers designed for wine storage. In the case of serial/sequential evaporators, the overall heat transfer surface area is also increased, which may lend incremental improvements in energy efficiency.

As discussed in section 3.3.1.2, DOE is aware of coolers with multiple cooling zones. These designs are more likely to utilize multiple evaporators for precision temperature control. Combination cooler refrigeration cooler products may also use multiple evaporators due to the multiple compartment operating temperatures.

3.3.3.6 Condenser

The condenser is another key component of the refrigeration system and is located outside of the refrigerated compartment. There are three basic condenser designs: a forced-convection finned-tube or wire-and-tube design; a wire-and-tube "static" design which uses natural convection cooling; and a hot wall condenser that is integrated within the shell of the unit. Similar to the evaporator, condenser performance can be enhanced by increasing the heat exchanger surface area or improving the heat exchange performance.

Increased Surface Area

Increasing the heat transfer surface area of condensers can be achieved by (a) increasing the width of the rows of tubes, (b) adding more tube rows along the direction of air flow, or (c) adding more tube rows across the direction of air flow. These measures can be limited by the geometry of the product. Increasing tube width can also result in an increased refrigerant pressure drop across the condenser, so there is a tradeoff between improving heat transfer and increasing compressor work. Similarly, adding tube rows can increase the air pressure drop through the condenser, so there is a tradeoff between improving heat transfer and increasing fan work.

As discussed in chapter 5 of this TSD, DOE has recently observed MREFs constructed with additional high-side refrigerant piping, which effectively increases the condensing surface area. Some models may use a combination of hotwall condenser and a forced-convection condenser to increase heat transfer surface area. Refrigerant anti-sweat heat also effectively extend the condenser surface area.

Tube and Fin Enhancements

As for evaporators, improving heat exchanger performance can be achieved through the use of enhanced fins and/or tubes. Other heat exchanger technologies could also be employed to improve condenser performance. As with evaporators, microchannel heat exchangers are also applicable to condensers.

Forced-Convection Condenser

Many full-size coolers use forced-convection condensers. However, some smaller, undercounter and "countertop" coolers use hotwall condensers. The forced convection condenser configuration can provide higher heat transfer effectiveness with the tradeoff being that this arrangement necessitates the use of a condenser fan, which consumes additional power. However, space for housing a forced convection condenser and its associated fan is not always available. The consideration of conversion to forced-convection condensers will depend on whether a particular product is designed in a way that allows housing of the condenser and fan in a suitable location.

3.3.3.7 Defrost System

Most MREFs simply defrost during their off-cycles; however, there are certain designs that use electric heaters to defrost the evaporator. Energy use associated with defrost includes the energy input for the heater and also the refrigeration system energy used to remove the defrost heat from the cabinet.

Off-Cycle Defrost

Because MREFs typically maintain warmer storage temperatures in than refrigerators and freezers, they have less need for active defrost. Therefore, energy savings can be achieved by using off-cycle (passive) defrost rather than active heater defrost when compartment temperatures are sufficiently warm.

Reduced Energy for Active Defrost

In some cases, the defrost heat supplied is more than required. Thus, energy savings can be achieved by reducing the defrost heat by either using a smaller heater, reducing the heater on-time, reducing the frequency of defrost, or a combination of these options. There may be limited additional energy savings possible through optimization of active defrost.

Adaptive Defrost

To reduce the energy used for active defrost, adaptive defrost (also known as “variable defrost control”) can be used. An adaptive defrost system can control both the defrost time and the amount of defrost heat. Adaptive defrost systems make use of controls to adjust the time between defrost cycles to the appropriate amount for the door opening frequency, ambient conditions, and other consumer usage patterns, which affect the introduction of moisture into the cabinet. In a typical automatic defrost system, a mechanical or electronic timer initiates defrost after a specified time period, usually 10 to 12 hours of compressor on-time. By allowing adjustment of the time between defrosts, energy use can be reduced. The DOE energy test procedure includes instructions for evaluating the energy use of products with adaptive defrost.

Condenser Hot Gas

Another method of reducing the energy required for defrost is to eliminate the need for electric heaters by substituting hot refrigerant gas from the condenser in their place. In a condenser hot gas defrost system, the compressor continues to run and a valve opens allowing hot compressed refrigerant to flow to the evaporator. Many frost-free refrigerator-freezers in the 1960s and 1970s used such a defrost system. DOE has not observed these systems in its direct analysis of MREFs.

3.3.3.8 Control System

MREFs can include systems to control the temperature and air-distribution within the refrigeration product.

Temperature Control

Conventional thermostats are thermomechanical devices to monitor temperature. The inaccuracy of these devices may produce large temperature fluctuations within the cabinet and, in turn, thermodynamic inefficiencies. Electronic thermostats are available that can provide more precise and repeatable temperature control than conventional thermostats. This can result in improved efficiency.

NEEA also noted that electronic thermostat systems can help reduce energy consumption by limiting temperature fluctuations. (NEEA, No. 7 at p. 3)

Electronic temperature control systems can also account for more parameters than just the cabinet temperature, such as the room temperature, to better regulate product operation and reduce compressor run times. Electronic temperature controls appear to have a high saturation in the current MREF market.

Air Distribution Control

For combination cooler refrigeration products, better air distribution between the different compartments can improve temperature control and reduce energy consumption. Improving the distribution of cold air within a compartment also allows the temperature difference between the air and the refrigerated goods to be minimized, enabling the evaporation temperature to be raised and, thereby, reducing energy consumption. Additionally, for combination cooler refrigeration products, better air distribution between the different compartments can improve temperature control and reduce energy consumption.

NEEA provided similar comments, stating that uniform cabinet temperatures enable more effective use of cooled air and reduce the overuse of the cooling system. NEEA also suggested that airfoil-shaped fan blades and airflow straighteners can reduce air turbulence and as a result increase the efficiency of air distribution systems in the refrigerated cabinet. (NEEA, No. 7 at p. 3)

DOE observed several models marketed to use advanced air distribution controls with the goal of achieving a uniform compartment temperature, but it is uncertain to what degree the air distribution control in current MREF models can be improved. However, the fact that several patents have been issued in the U.S. since 1995 regarding air distribution implies that improvements in air distribution control are possible.[33]

3.3.3.9 Other Technologies

Fan and Fan Motor Improvements

Because many MREFs use forced-convection evaporators and condensers which rely on fans for air movement, fan and fan-motor technology options for the evaporator and condenser are typically applicable. However, certain MREF designs use static condensers, hotwall condensers and/or natural convection evaporators which are not always coupled with fans, so these improvements would not apply to those designs.

For those refrigeration products that do utilize fans, manufacturers typically purchase fans and fan motors from outside vendors. Therefore, conversion to more-efficient fan motors can be accomplished relatively easily when more-efficient fans and fan motors are available.

Forced convection evaporators and condensers typically rely on axial fans. Evaporator fan blades are typically either 100 mm or 110 mm in diameter. Because the evaporator fan and fan motor are located within the refrigerated cabinet and the electric energy input adds to the refrigeration load, more-efficient evaporator fan or evaporator fan motor designs contribute to efficiency improvements in two ways: (1) reducing the power consumption of the fan motor and (2) reducing the power consumption of the compressor due to decreased heat losses into the cabinet from the fan motor.

Higher-efficiency motor designs include permanent split capacitor (PSC) induction motors with 20 to 30 percent efficiency, and brushless DC (BLDC) motors, with approximately 66 percent efficiency. NEEA provided that not only are BLDC fan motors more efficient, but they also reduce operational noise. (NEEA, No. 7 at p. 3)

DOE notes that as costs for BLDC motors have dropped, many manufacturers have shifted to BLDC fan motors.

Expansion Valve Improvements

MREFs use capillary tube metering devices. As discussed above in section 3.3.2.5, there are two common types of capillary tubes—adiabatic and non-adiabatic. In the non-adiabatic configuration, the capillary tube is soldered to the suction line to evaporate the residual liquid in the suction line and to warm the vapor to near-ambient temperature. The suction line heat exchanger (or the non-adiabatic capillary) improves efficiency because it increases the refrigeration capacity of the system by the amount of heat being transferred from the capillary to the suction side. Non-adiabatic capillary tubes are the most common type of metering device in refrigeration products. The other type of metering device, an adiabatic capillary tube, is used in some refrigeration products. In this configuration, the capillary tube does not exchange heat with the suction line and the refrigerant expands from the high pressure to the low pressure adiabatically. Research has been conducted to develop models to study the performance of both types of capillary tubes.[62, 63]

Automatic, adjustable thermostatic or electronic expansion valves may provide improved performance. The technology for this design option is available; however, a modification in system design is required. DOE has not been able to identify any data demonstrating that improved expansion valves will save energy in MREFs.

Fluid Control or Solenoid Valve

Off-cycle refrigerant migration reduces a refrigeration product's efficiency by transferring heat from outside the cabinet into the evaporator. Changes in the design of the refrigeration cycle that reduce refrigerant migration can increase the unit's efficiency.

A fluid control or solenoid valve installed after the condenser to effectively isolate the evaporator from the condenser during the off-cycle can be used to prevent any refrigerant migration. Research has demonstrated that solenoid valves can yield substantial energy savings.[64] However, there are drawbacks to using solenoid valves. First, refrigeration migration allows the system pressure to equalize, reducing the required starting torque of the compressor motor. A solenoid valve would increase the required starting torque of the compressor motor. Second, adding such a valve could negatively affect system reliability.

Alternative Refrigerants

Through the 1980s, CFC-12, a chlorofluorocarbon, was used as the refrigerant in almost all refrigeration products. However, under the Montreal Protocol, all CFCs were banned from use by the mid-1990s due to their high ozone depletion potential ("ODP"). In the early 1990s, many alternative refrigerants were evaluated as a replacement for CFC-12. Of the alternatives considered, the industry settled on HFC-134a (also known as R-134a) as the replacement for CFC-12. Although initial research demonstrated that R-134a as a drop-in replacement yielded efficiencies which were four to 10 percent less than CFC-12, further work showed that with the appropriate superheat and subcooling taken into consideration, R-134a could yield essentially equivalent system efficiencies as CFC-12.[65]

Because of the high GWP of R-134a (1430), research continued to find an alternative refrigerant with less or no GWP. Naturally occurring substances such as carbon dioxide, ammonia, and hydrocarbons are all considered to be environmentally safe refrigerants with very low GWP. Hydrocarbons in particular are attractive due to their similar thermodynamic properties to CFC-12. Much research has been conducted showing the efficiency benefits of hydrocarbons. For example, the performance of propane/isobutane and propane/butane mixtures in refrigeration products has been shown to be equal to or better than products using CFC-12.[66, 67] European refrigerator manufacturers started manufacturing products with isobutane in the 1990s. The introduction of hydrocarbon refrigerants in the U.S. market was slower due to flammability concerns.

On December 1, 2016, EPA published a final rule in the *Federal Register* under its Significant New Alternatives Policy ("SNAP") program that changed the status from acceptable to unacceptable of certain refrigerants (*e.g.*, R-134a) commonly used in MREFs as of January 1, 2021. 81 FR 86778. On April 27, 2018, EPA published a notice stating that following a partial-vacatur of a July 20, 2015, final rule under the SNAP program listing as unacceptable the use of certain HFCs (see Mexichem Fluor, Inc. v. EPA, 866 F.3d 451 (D.C. Cir. 2017) it will not apply HFC listings relevant to refrigeration products pending a rulemaking and that it plans to begin a notice-and-comment rulemaking process. 83 FR 18431.

EPA determined three flammable refrigerants—isobutane (R-600a), propane (R-290), and R-441A—acceptable, subject to use conditions, in new refrigeration products under the SNAP program. 76 FR 78832, December 20, 2011; 80 FR 19454, April 10, 2015. In an update to this rule ("August 2018 SNAP Rule", 83 FR 38969, August 8, 2018), the use conditions for these flammable refrigerants were revised to reflect the 2nd edition of the Underwriters Laboratories (UL) Standard for Safety: Household and Similar Electrical Appliance - Safety - Part 2-24: Particular Requirements for Refrigerating Appliances, Ice-Cream Appliances and Ice-Makers, UL 60335-2-24, dated April 28, 2017.

NEEA commented that natural refrigerants have the potential to increase system efficiency by up to 30%, and that the small size of MREFs would require only small amounts of flammable refrigerant charge. (NEEA, No. 7 at pp. 3-4)

DOE has noted that R-600a refrigeration systems have become very common in MREFs. DOE understands that the transition from HFC refrigerants to hydrocarbons (most commonly R-600a for MREFs) typically results in reduced energy consumption; however, the precise efficiency improvement is dependent upon a multitude of factors, including (but not limited to) the designs of compressors and heat exchangers compatible with these refrigerants. While the use status of HFCs is somewhat uncertain, the use of R-600a refrigerant is permitted in the U.S. market under the August 2018 SNAP Rule.

Improved Refrigerant Piping

In response to the December 2020 Early Assessment RFI, NEEA indicated that lowering the pressure drop in refrigerant piping in MREFs may lead to efficiency gains. Specifically, NEEA stated that replacing sharp corners with more gradual transitions in refrigerant piping can reduce energy use by 8%.[l] (NEEA, No. 7 at p. 4)

Pressure drops in refrigerant piping typically result in a reduction in cooling capacity from the refrigeration system. DOE notes that gradual transitions in refrigerant piping (such as a bend with a larger radius of curvature) would require larger cabinet dimensions in order to accommodate the same components, and therefore such designs may not be feasible without increasing cabinet size or reducing refrigerated volume.

Component Location

Optimal placement of certain components may result in energy savings. For example, if the compressor and condenser are located on the top of the product, heat can more readily be convected away from the system. As described previously, traditionally, the compressor and condenser are located at the bottom rather than the top of the product so the user can have easy access to the food compartments, to keep center of gravity low, and to provide air flow and a heat source near the tray which collects defrost water to assure quick re-evaporation of water. Locating the condenser and compressor at the top of the unit would require modification of traditional practice and consumer preference. It would also require product redesign, which could potentially increase manufacturing costs.

Another option is to locate the evaporator fan motor outside the cabinet to reduce internal loads from the heat loss of the motor. However, it is difficult to prevent air leakage where the motor shaft penetrates the cabinet wall. DOE is not aware of data indicating the feasibility of this design change.

Alternative Refrigeration Systems

Alternative refrigeration systems do not use vapor compression to provide refrigeration. DOE previously considered thermoelectric cooling technologies as part of the October 2016 Direct Final Rule analysis and found that vapor-compression refrigeration represented the most efficient cooling method. DOE did not directly analyze thermoelectric cooling systems in this preliminary analysis due to the limited number of commercially available MREFs using this technology.

NEEA commented that electrocaloric cooling systems have the potential to be less energy-intensive than vapor compression refrigeration.[m] NEEA also stated that thermoelastic and magnetocaloric methods of refrigeration discussed in a 2014 report by DOE may be able to be scaled down and retain higher efficiency than vapor compression. (NEEA, No. 7 at p. 4)

Aprea *et. al.* indicate that electrocaloric cooling is somewhat analogous to magnetocaloric cooling: certain materials undergo a change in temperature when subject to a change in electric field. While the magnetocaloric effect applies to all magnetic materials, only specific materials exhibit the electrocaloric effect. Ferroelectric polymer films were hypothesized

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[l] NEEA cited a 2011 study by Liu *et. al.* titled "Experimental study on household refrigerator with diffuser pipe," available at doi.org/10.1016/j.applthermaleng.2011.01.022.

[m] NEEA cited a 2016 study by C. Aprea *et. al.* titled "Electrocaloric refrigeration: an innovative, emerging, eco-friendly refrigeration technique," available at iopscience.iop.org/article/10.1088/1742-6596/796/1/012019.

to be the most promising electrocaloric materials. While the study indicated theoretical COPs as high as 10 are possible, it is not stated whether the components used in this technology option can be sized down for commercial viability in standalone MREFs.[68]

In March 2014, DOE published a report discussing non-vapor-compression heating and cooling technologies (titled "Energy Savings Potential and RD&D Opportunities for Non-Vapor-Compression HVAC Technologies"). In this report, DOE determined that thermoelastic and magnetocaloric cooling could theoretically lead to energy savings over traditional vapor-compression systems; however, this assessment was made only for space cooling and heating applications, and these technologies were not considered for refrigeration products.[69]

A 2021 study by researchers at the Federal University of Santa Catarina made direct comparisons between vapor-compression cooling and magnetocaloric cooling systems in MREFs. The experiment measured the COP of a cooler with a vapor-compression system and then the COP of the same cooler with the vapor-compression system replaced by a magnetocaloric system. The results showed that the vapor-compression system had a higher COP than the magnetocaloric prototype. Additionally, the magnetocaloric system could not be fully encased within the cabinet to create a standalone product.[70]

DOE is not aware of these alternative refrigeration systems in commercially available MREFs.

3.3.4 Energy Efficiency

DOE gathered data on the energy efficiency of MREFs currently certified by manufacturers in reviewing DOE's CCMS. The CCMS includes a wide breadth of data for each certified model, including brand, model number, product class, adjusted volume, refrigerated volume, and annual energy use. DOE plotted the adjusted volume and certified annual energy use for each product class with curves representing the current maximum allowable energy consumption (*i.e.*, the current energy conservation standard) and current ENERGY STAR level. Combining the product data with the current MREF energy conservation standards provides a visual overview of the energy efficiency of each product class covered by this rulemaking.

For all covered product classes, DOE analyzed and plotted all models in the CCMS; however, certain product classes did not have any certified models in the CCMS database. See Appendix 3A of this TSD for these plots.

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CHAPTER 4. SCREENING ANALYSIS

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4.1 INTRODUCTION

This chapter discusses the screening analysis conducted by the U.S. Department of Energy ("DOE") of the technology options identified in the market and technology assessment for miscellaneous refrigeration products ("MREFs") (chapter 3 of this technical support document ("TSD")). In the market and technology assessment, DOE presented an initial list of technologies that could potentially be used to reduce energy consumption of MREFs. The goal of the screening analysis is to identify any technology options that will be eliminated from further consideration in the rulemaking analyses.

DOE must follow specific statutory criteria for prescribing new or amended standards for covered products. The Energy Policy and Conservation Act ("EPCA") requires that any new or amended energy conservation standard prescribed by the Secretary of Energy ("Secretary") be designed to achieve the maximum improvement in energy or water efficiency that is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) The Secretary may not prescribe an amended or new standard that will not result in significant conservation of energy, or is not technologically feasible or economically justified. (42 U.S.C. 6295(o)(3)) As stated, DOE determines whether to eliminate certain technology options from further consideration based on the following criteria:

(1) **Technological feasibility.** Technologies that are not incorporated in commercial products or in working prototypes will not be considered further.

(2) **Practicability to manufacture, install, and service.** If it is determined that mass production of a technology in commercial products and reliable installation and servicing of the technology could not be achieved on the scale necessary to serve the relevant market at the time of the effective date of the standard, then that technology will not be considered further.

(3) **Impacts on product utility or product availability.** If a technology is determined to have significant adverse impact on the utility of the product to significant subgroups of consumers, or results in the unavailability of any covered product type with performance characteristics (including reliability), features, size, capacities, and volumes that are substantially the same as products generally available in the United States at the time, it will not be considered further.

(4) **Adverse impacts on health or safety.** If it is determined that a technology will have significant adverse impacts on health or safety, it will not be considered further.

(5) **Unique-Pathway Proprietary Technologies.** If a technology option uses proprietary technology that represents a unique pathway to achieving a given efficiency level, that technology will not be considered further.

10 CFR part 430, subpart C, appendix A, 6(c)(3) and 7(b).

The candidate technology options are assessed based on DOE analysis as well as inputs from interested parties, including manufacturers, trade organizations, and energy efficiency advocates. Technology options that are judged to be viable approaches for improving energy efficiency are retained as inputs to the subsequent engineering analysis, and are designated as "design options."

4.2 DISCUSSION OF TECHNOLOGY SCREENING

For MREFs, the screening criteria specified in section 4.1 were applied to the technology options to either retain or eliminate each technology for consideration in the engineering analysis. The rationale for either screening out or retaining each technology option considered in this analysis is detailed in the following sections.

4.2.1 Screened Design Options

Based on DOE's research and consideration of comments received from interested parties, DOE screened out the technology options shown in Table 4.2.1.

Table 4.2.1 Screened Out Technology Options

Technology Option	EPCA Criterion (X = basis for screening out)				
	Technological Feasibility	Practicability to Manufacture, Install, and Service	Adverse Impacts on Utility or Availability	Adverse Impacts on Health and Safety	Unique-Pathway Proprietary Technologies
Solid Doors			X		
Ultra-low-E (reflective) Glass Doors			X		
Vacuum-Insulated Glass		X			
Improved Gaskets and Double Gaskets			X	X	
Linear Compressors			X		X
Fluid Control or Solenoid Off-Cycle Valves		X	X		
Evaporator Tube and Fin Enhancements			X		
Condenser Tube and Fin Enhancements (except microchannel condensers)			X		
Condenser Hot Gas Defrost	X				
Improved Refrigerant Piping			X		
Component Location		X	X	X	

Technology Option	EPCA Criterion (X = basis for screening out)				
	Technological Feasibility	**Practicability to Manufacture, Install, and Service**	**Adverse Impacts on Utility or Availability**	**Adverse Impacts on Health and Safety**	**Unique-Pathway Proprietary Technologies**
Alternative Refrigeration Systems	X	X	X		
Improved VIPs	X	X			

In an early assessment review and request for information ("RFI") published on December 8, 2020 (the "December 2020 Early Assessment RFI"), DOE requested information on newly identified technology options which could potentially improve the efficiency of MREFs. 85 FR 78964. DOE received comments from interested parties regarding the use of certain technology options and used these comments to help identify options to screen out from the engineering analysis.

Sub Zero commented that built-in MREFs have limitations because these designs may have restricted condenser airflow, longer door gasket length per unit of storage volume, limits to insulation thickness, and complicated door hinging that increases cabinet heat load. (Sub Zero, No. 8, pp. 1-2) NEEA encouraged DOE to consider volume constraints for MREFs in general, suggesting that MREF products tend to have less space in the cabinet compared to larger refrigerators. NEEA also noted that it is possible to shrink one component of a refrigeration system and/or allow for an increase in the volume of a larger component, and that DOE should consider these volume trade-offs. (NEEA, No. 7, p. 4)

In conjunction with its own evaluation, DOE has considered the NEEA and Sub Zero assessments of technology options in the current market. At this time, DOE is not screening out the technology options identified by NEEA and Sub Zero as none of the five screening criteria appears applicable. DOE did consider potential impacts on consumer utility, including cabinet sizes and internal volumes, as part of the engineering analysis for these design options. See chapter 5 of this TSD.

4.2.1.2 Solid Doors

In response to the December 2020 EA RFI, AHAM indicated that solid doors would result in improved efficiency but at the significant cost of consumer utility. AHAM specified that the glass door is a major feature for MREFs, and a major motivation for consumers in purchasing MREFs is the ability to see the contents of their coolers. (AHAM, No. 3, p. 3)

DOE screened out solid doors from further consideration in this preliminary analysis under screening criterion #3 based on the consumer utility of glass doors, as described by AHAM. Solid doors were likewise screened out from the engineering analysis of cooler compartment doors in the previous rulemaking. See chapter 4 of the October 2016 Direct Final

Rule TSD[a]. Discussions with manufacturers have indicated that coolers with solid doors would be much less desirable to consumers, hence DOE has eliminated this option from further consideration, and has only analyzed efficiency levels that are achievable using glass doors.

4.2.1.3 Ultra-Low-E Glass Doors

Chapter 3 of this TSD discusses the efficiency benefits of low-emissivity glass for MREF doors. Ultra-low-emissivity glass can be produced by multiple layers of soft-coat application or by an adhesive tint. In its market assessment, DOE has identified several MREFs which use this type of glass. For example, some coolers marketed to store temperature-sensitive beauty products may come with this feature.[1] Although ultra-low-emissivity glass could yield substantial improvements in efficiency, it impedes the visibility of the interior of the refrigerated cabinet. Similar to solid doors, DOE has excluded this type of glass from further consideration.

4.2.1.4 Vacuum-Insulated Glass

As discussed in chapter 3 of this TSD, vacuum-insulated glass is a technology option currently available for use in refrigeration equipment, specifically for in walk-in cooler doors. DOE is not aware of vacuum-insulated glass currently in use for any MREFs. Because MREFs are typically much smaller than commercial refrigeration equipment, vacuum-insulated glass may not yet be available for all MREF sizes. Thus, DOE has screened vacuum-insulated glass from further consideration because it may not be practicable to manufacture for the entire MREF market.

4.2.1.5 Improved Gaskets and Double Gaskets

As discussed in the TSD for the September 2011 Final Rule (Sept. 15, 2011; 76 FR 57516) which established the current refrigerator, refrigerator-freezer, and freezer energy conservation standards[b], past investigation on reduction of heat load in the gasket and door face frame area has focused on (1) limiting the conduction of heat through metal casing material passing underneath the gasket magnet on the cabinet side or in the region of the gasket clip on the door side into the cabinet interior, (2) using a gasket which provides additional cover of frame surfaces towards the interior of the magnet to prevent cold air from reaching the high-conductivity metal casing near the gasket magnet, and (3) providing a long thin "throat" area between the gasket and the interior to limit convection heat transfer. Most current designs, including for MREFs, are effective in addressing these issues.

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[a] Available online at www.regulations.gov/document/EERE-2011-BT-STD-0043-0118.

[b] Available in docket EERE-2008-BT-STD-0012 at www.regulations.gov/document/EERE-2008-BT-STD-0012-0128.

As discussed in chapter 3 of this TSD, double door gaskets can further reduce heat leakage and infiltration into the cabinet. However, these gaskets can increase the difficulty of meeting safety regulations for minimum door-opening force.

Limited information is publicly available which would allow quantification of additional improvement potential for the door frame/gasket area of refrigerators. Some manufacturers use extra-strong gasket magnets to limit infiltration and thermal loss, but it is unclear whether significant thermal improvement is possible with such systems. In the September 2011 Final Rule analysis, DOE noted that during technical discussions, manufactures indicated that properly designed and installed gasket systems provide a tight seal and that there is no further reduction in air leakage that could be achieved with improvements in the gasket system such as increasing the magnetic force. In addition, consumer safety laws preclude use of excessive door sealing force, indicating that these designs may have adverse impacts on health and safety.

4.2.1.6 Linear Compressors

Many of the performance benefits associated with linear compressors are also observed with variable-speed compressors. In the September 2011 Final Rule analysis, DOE noted that manufacturers who have indicated that they have investigated linear technology have stated that linear compressor technology does not provide a clear path to improved efficiency, and some have indicated that they are no longer actively pursuing this technology (see chapter 4 of the September 2011 Final Rule TSD). Based on what DOE observed during reverse engineering, DOE expects that manufacturers would likely implement variable-speed compressors rather than linear compressors to improve efficiencies.

DOE has observed linear compressors available in LG refrigeration products. As discussed in chapter 3 of this TSD, DOE is aware that another compressor manufacturer, Embraco offers linear compressors for use in refrigeration products, which Embraco claims may increase efficiency by 40 percent. However, Embraco's Wisemotion linear compressor may only be available for use by specific RF manufacturers. Additionally, both LG and Embraco have active patents on linear compressor technologies (US Patents Nos. US10634127B2 and US9915260B2). Thus, DOE did not further consider linear compressors and instead considered variable-speed compressors in the engineering analysis, which offer many of the same benefits as linear compressors.

4.2.1.7 Fluid Control or Solenoid Off-Cycle Valves

Off-cycle refrigerant migration reduces a refrigeration product's efficiency by allowing warm and/or vapor-phase refrigerant to pass into the cabinet. A fluid control or solenoid valve installed after the condenser to effectively isolate the evaporator from the condenser during the off-cycle can be used to prevent refrigerant migration.

Research has demonstrated that solenoid valves can yield substantial energy savings[2]. Such a solenoid valve represents a possible reliability issue, although many wine storage products use similar solenoid valves to allow control of multiple compartments with a single compressor. Also, operation with an off-cycle valve requires that the compressor motor can start up against a substantial pressure difference. The starting windings of compressors that can do this reliably over the life of a refrigerator draw more power and hence reduce the compressor's steady-state efficiency. The different efficiency levels of commercial refrigeration compressors designed for instant restart versus restart after pressure equalization have efficiency ratings which differ by 10% or more. Such a difference would be expected for consumer compressors operating with an off-cycle valve, and this difference would more than neutralize any benefit accrued from using the off-cycle valve.

Due to reliability concerns and the resulting impact on the product's utility and practicability to manufacture, install, and service, DOE has eliminated fluid control or solenoid off-cycle valves from further consideration.

4.2.1.8 Evaporator Tube and Fin Enhancements

Improving heat exchanger performance can be achieved through the use of enhanced fins and/or tubes (including microchannel evaporators). These types of fin and tube enhancements are common in air-conditioning applications where slit and louvered designs are used to enhance the fin surface and different types of internally-grooved surfaces are used to enhance the tubing. Application of similar enhancements in refrigeration product evaporators is complicated by frost accumulation. Effectiveness of the fine slit and louver features for evaporators is uncertain because they could be blocked quickly with frost. In order to avoid the energy use associated with frequent defrost, fin spacing in refrigeration product evaporators is comparatively sparse. This allows the evaporator to work effectively without blocking airflow with a considerable accumulation of frost. During defrost, the typical flat fin design of these evaporators assures that the frost slides rapidly off the fins and does not get stuck on fin enhancement features.

DOE has eliminated this option from further consideration in this analysis as products currently utilize enhanced evaporator designs to the extent possible, and any further incremental improvements would likely affect product utility due to potential issues with frost build-up.

4.2.1.9 Condenser Tube and Fin Enhancements

Use of heat exchanger enhancements for the condenser is complicated by the need for adequate performance when the heat exchanger has not been cleaned. Most refrigeration product condensers (other than hot wall condensers integrated into the outer shells of the products) are made of steel tubes and steel wire fins. These condensers have a very open construction which allows dust to flow through easily and which reduces blockage of air flow if dust does collect on the condenser surfaces. Flat fin condensers used in refrigerators are known to require more careful attention to cleaning. Use of high fin densities is more accepted in air-conditioning applications because periodic maintenance is expected and because size would be an issue if aggressive fin spacing was not employed, whereas cleaning of refrigerator condensers occurs infrequently or never, and the loads are small enough so that maximizing use of space is not critical.

Thus, DOE has eliminated this option from consideration in subsequent analysis, with the exception of microchannel condensers, which are discussed in chapter 5 of this TSD.

4.2.1.10 Condenser Hot Gas Defrost

Another method of reducing the energy required for defrost is to eliminate the need for electric heaters by substituting condenser hot gas in their place. In a condenser hot gas defrost system, the compressor continues to run and a valve opens allowing hot compressed refrigerant to flow to the evaporator. Hot gas defrost would potentially save energy because a large portion of the heat for defrost could be provided by heat generated by the compressor motor during the on-cycle rather than from new electricity use. The compressor is at an elevated temperature with respect to ambient during the on-cycle and is much warmer than freezing temperature. The heat would be transported to the evaporator with circulating refrigerant during the defrost cycle. However, despite this potential reduction in use of electricity to provide defrost heat, the energy savings potential is not well documented. Also, there are concerns regarding reliability of the required valve.

DOE did not observe a condenser hot gas defrost for any of the products in its engineering sample. Given the potential issues with incorporating such a defrost and questions regarding the potential for energy savings, DOE has not considered this technology in the engineering analysis.

Improved Refrigerant Piping

As discussed in chapter 3 of this TSD, pressure drops in refrigerant piping typically result in a reduction in cooling capacity from the refrigeration system, thus decreasing refrigeration system efficiency. DOE notes that design changes to reduce pressure drops, such as bends with a larger curve radius, would likely require larger cabinet dimensions in order to accommodate the same components, and therefore such designs may not be feasible without increasing cabinet size or reducing refrigerated volume. Specifically, DOE observed that to the extent feasible, manufacturers already implement gradual piping bends – *e.g.*, for hot wall condensers. In other locations, such as around the condenser, space is more constrained and tighter bends are necessary to fit the necessary components within the cabinet.

Due to the potential for impacts on consumer utility, DOE has screened out optimized refrigerant piping as a design option for further consideration.

4.2.1.11 Component Location

Locating the compressor at the top of the MREF (to reduce heat leak to the refrigerated compartment) would increase the structural requirement for the cabinet, increase risk of product tip-over, and provide less practical use of space from the consumer perspective. It also makes design for re-evaporation of defrost water more challenging. It is unlikely that the savings would justify all of these drawbacks.

Another option is to locate the evaporator fan motor outside the cabinet to reduce internal loads from the heat loss of the motor. Given the low fan motor input wattages and shift to increasing fan motor efficiencies, the load reduction associated with moving the fan motor loss outside the cabinet is likely comparable to the added infiltration and conduction associated with moving the fan components outside of the refrigerated cabinet.

DOE has not identified any options for relocation of components for further consideration in the engineering analysis and has screened out this design option from further consideration due to the potential for negative consumer impacts and technical feasibility.

4.2.1.12 Conversion to Alternative Refrigeration Systems

As discussed in the October 2016 Direct Final Rule TSD, thermoelectric cooling technology currently does not achieve efficiency levels which make it attractive as a design option alternative to vapor-compression technology for improving cooler energy efficiency. Additionally, DOE notes that conversion to a thermoelectric refrigeration system may limit the capability of coolers to maintain compartment temperatures when operating in a warm ambient temperature.

Additionally, the other alternative refrigeration systems identified in chapter 3 of this TSD, electrocaloric, thermoelastic, and magnetocaloric, are not yet mature technologies and would not be practicable to manufacturer for the MREF market more broadly.

Accordingly, DOE has screened alternative refrigeration systems from further consideration as a design option in the engineering analysis.

4.2.1.13 Improved Vacuum-Insulated Panels

DOE considered VIPs as a design option in the October 2016 Direct Final Rule analysis. Since then, additional research has indicated that improvements to VIP technology are technically possible; however, DOE has not identified commercially viable improved VIPs available for use in refrigeration products.

For this analysis, DOE has continued to consider VIPs as a design option in the engineering analysis, as discussed in chapter 5 of this TSD, but has screened out incremental improvements to VIPs from the engineering analysis.

4.2.2 Retained Design Options

Table 4.2.2 lists the design options for consumer refrigerators, refrigerator-freezers, and freezers that were retained by DOE. DOE evaluated each of these technologies further in the subsequent engineering analysis. Chapter 5 of this TSD includes discussion of these retained design options and DOE's basis for whether it incorporated each of them in the cost-efficiency relationship developed in the engineering analysis.

Table 4.2.2 Retained Design Options

Insulation	**Condenser**
Improved resistivity of insulation (insulation type)	Increased surface area
Increased insulation thickness	Microchannel designs
Vacuum-insulated panels	Forced-convection condenser
Gas-filled insulation panels	**Defrost System**
Gaskets and Anti-Sweat Heat	Off-cycle defrost
Anti-sweat heat	Reduced energy for automatic defrost
Doors	Adaptive defrost
Low-E coatings	**Control System**
Inert gas fill	Electronic Temperature control
Additional Panes	Air-distribution control
Frame design	**Other Technologies**
Compressor	Fan and fan motor improvements
Improved compressor efficiency	Improved expansion valve
Variable-speed compressors	Alternative refrigerants
Evaporator	
Increased surface area	
Forced-convection evaporator	
Multiple evaporators	

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CHAPTER 5. ENGINEERING ANALYSIS

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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 consumption and costs of miscellaneous refrigeration products ("MREFs") at various levels of increased efficiency. This chapter provides an overview of the engineering analysis (section 5.1), discusses product classes (section 5.2), explains the methodology used during data gathering and analysis (section 5.3), details baseline and incremental efficiency levels (section 5.4), outlines the energy modeling used in this analysis (section 5.4), lists and analyzes design options (section 5.5), and discusses 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 were determined through teardown analysis.

The primary considerations in the engineering analysis are the selection of efficiency levels to analyze (*i.e.*, the "efficiency analysis") and the determination of product cost at each efficiency level (*i.e.*, the "cost analysis").

DOE conducts the efficiency analysis using an efficiency-level approach, a design-option approach, or a combination of both. Under the efficiency-level approach, the efficiency levels to be considered in the analysis are determined based on the market distribution of existing products (in other words, observing the range of efficiency and efficiency level "clusters" that already exist on the market). This approach typically starts with compiling a comprehensive list of products available on the market, such as from DOE's compliance certification management system ("CCMS")[a] database. Next, the list of models is ranked by efficiency level from lowest to highest, and DOE typically creates a scatter plot to visualize the distribution of efficiency levels. From these rankings and visual plots, efficiency levels can be identified by examining clusters of models around common efficiency levels. The maximum efficiency level currently available on the market can also be identified.

Under the design option approach, the efficiency levels to be considered in the analysis are determined through detailed engineering calculations and/or computer simulations of the efficiency improvements from implementing specific design options that have been identified in the technology assessment. In an iterative fashion, design options can also be identified during product teardowns, described below. The design option approach is typically used when a comprehensive database of certified models is unavailable (for example, if a product is not yet regulated) and therefore the efficiency-level approach cannot be used.

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[a] Accessible at *www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A**.

In certain rulemakings, the efficiency-level approach (based on actual products on the market) will be extended using the design option approach to interpolate to define intermediate levels (to bridge large gaps between other identified efficiency levels) and/or to extrapolate to the "max tech" level (the level that DOE determines is the maximum achievable efficiency level), particularly in cases where the "max tech" level exceeds the maximum efficiency level currently available on the market.

In the engineering analysis supporting the direct final rule published in the *Federal Register* on October 28, 2016, ("the October 2016 Direct Final Rule"), DOE used a hybrid approach of the different analysis approaches. (See chapter 5 of the October 2016 Direct Final Rule TSD, available online at *www.regulations.gov/document/EERE-2011-BT-STD-0043-0118*). There were no existing DOE standards for MREFs at the time of the previous rulemaking, and the engineering analysis was informed by State efficiency databases, teardown analyses, and input provided by the Appliance Standards and Rulemaking Federal Advisory Committee ("ASRAC") Working Group established for MREFs.

For this preliminary engineering analysis, DOE followed a similar general approach as the October 2016 Direct Final Rule, using a combination of the design-option and efficiency level approaches to assess coolers. With energy conservation standards now in place, DOE generally relied on existing product efficiency levels for the baseline and initial higher efficiency levels (*i.e.*, the efficiency level approach), and considered additional incremental efficiency improvements based on the estimated energy use reduction associated with incorporating design options beyond those observed in the directly analyzed products (*i.e.*, the design option approach).

Combination cooler refrigeration products have far fewer models available on the market as compared to coolers. (See Appendix 3A to this TSD) Accordingly, DOE could not target combination cooler refrigeration products for analysis at key efficiency levels. Additionally, the unique manufacturer designs of combination cooler refrigeration products make it difficult to identify a representative unit design for analysis. Because combination cooler refrigeration products are similar to refrigerators, refrigerator-freezers, and freezers, DOE relied upon cost-efficiency curves derived from its preliminary engineering analysis for refrigerators, refrigerator-freezers, and freezers as the basis for this engineering analysis.[b] This approach would also enable DOE to consider potential energy conservation standards across all potential product classes of combination cooler refrigeration products, even those for which no models are currently available.

The cost analysis portion of the engineering analysis is conducted using one or a combination of cost approaches. The selection of the cost approach depends on variety of factors such as the availability and reliability of information on product features and pricing, the physical characteristics of the regulated product, and the practicability of purchasing the product on the market. DOE generally uses the following cost approaches:

[b] On October 15, 2021, DOE published a notice regarding its preliminary analysis to consider energy conservation standards for refrigerators, refrigerator-freezers, and freezers (the "2021 RFs Preliminary Analysis"). 86 FR 57378. The TSD for this analysis is found at *www.regulations.gov/document/EERE-2017-BT-STD-0003-0020*.

- Physical teardown: Under this approach, DOE physically dismantles a commercially available product, component-by-component, to develop a detailed bill of materials ("BOM") for the product.

- Catalog teardown: In lieu of physically deconstructing a product, DOE identifies each component using parts diagrams (available from manufacturer websites or appliance repair websites, for example) to develop the BOM for the product.

- Price surveys: If neither a physical nor catalog teardown is feasible (for example, for tightly integrated products that are infeasible to disassemble and for which parts diagrams are unavailable), DOE conducts retail price surveys by scanning retailer websites and other marketing materials. This approach must be coupled with assumptions regarding distributor markups and retailer markups in order to estimate the actual manufacturing cost of the product.

For this preliminary analysis, DOE used the physical teardown approach supplemented with a catalog teardown approach for coolers. For combination cooler refrigeration products, DOE conducted a physical teardown to determine manufacturer production costs ("MPCs") for one analyzed product class, but primarily relied on the engineering conducted for the 2021 RFs Preliminary Analysis as the basis for other MPCs and incremental costs.

The primary output of the engineering analysis is a set of tables identifying the incremental manufacturing cost, in relation to the manufacturing cost of the minimum-efficiency baseline product, required to produce products at each of the higher efficiency levels considered in the analysis. In the subsequent markups analysis (chapter 6), DOE determined customer (i.e., product purchaser) prices by applying manufacturer markups, distribution markups, and sales tax. 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).

This TSD chapter further describes the process DOE followed to establish its cost-efficiency relationships for MREFs in this preliminary analysis.

5.2 PRODUCT CLASSES ANALYZED

In the October 2016 Direct Final Rule analysis, DOE directly analyzed five product classes, listed in Table 5.2.1. See chapter 5 of the October 2016 Direct Final Rule TSD. For this preliminary engineering analysis, DOE directly analyzed the freestanding cooler and freestanding compact cooler product classes. As described, DOE did not directly analyze combination cooler refrigeration products, but did develop a cost-efficiency relationship for product class C-13A and presents a method for applying the 2021 RFs Preliminary Analysis engineering analysis as the basis for further consideration of combination cooler refrigeration products.

DOE considers the two directly analyzed product classes, along with C-13A, to be most representative of industry shipments for MREFs. These product classes are listed in Table 5.2.2. Additionally, the analysis of the directly analyzed classes is intended to be representative of similar product classes. For instance, the analysis for freestanding product classes is also representative of the cost-efficiency characteristics of the built-in product classes.

Table 5.2.1 Product Classes Directly Analyzed in the October 2016 Direct Final Rule Analysis

Product Class	Description
Cooler-FC	Freestanding compact coolers
Cooler-F	Freestanding coolers
C-3A	Cooler with all-refrigerator—automatic defrost
C-9	Cooler with upright freezers with automatic defrost without an automatic icemaker
C-13A	Compact cooler with all-refrigerator—automatic defrost

Table 5.2.2 Product Classes Directly Considered in this Preliminary Analysis

Product Class	Description
Cooler-FC	Freestanding compact coolers
Cooler-F	Freestanding coolers
C-13A	Compact cooler with all-refrigerator—automatic defrost

5.2.1 Built-In Product Classes

In the October 2016 Direct Final Rule, DOE used its analysis of freestanding and freestanding compact coolers to assess the cost-efficiency characteristics of built-in coolers and built-in compact coolers. DOE considered that the same pathways to max-tech efficiencies would be available for built-in MREFs and freestanding MREFs. However, because of the design constraints that can be associated with built-in products, built-in MREFs would likely not be capable of achieving the same max-tech efficiency as freestanding MREFs. To address this, in the October 2016 Direct Final Rule analysis, DOE applied a 10-percent energy use adder to its built-in product class analysis. This adder was derived from the difference between built-in and freestanding energy conservation standards for refrigerators, refrigerator-freezers, and freezers. See chapter 5 of the October 2016 Direct Final Rule TSD.

Similarly, DOE did not directly analyze built-in product classes for this preliminary analysis because: many freestanding MREFs (including those considered for this preliminary engineering analysis) are marketed to be capable of built-in installations and therefore would have similar design constraints, built-in products represent a very small portion of the overall MREF market (approximately 0.9 percent of all cooler shipments, see chapter 9 of this TSD), and the range of available efficiencies for built-in products on the market is similar to that for freestanding products.

Therefore, for this preliminary analysis, DOE has considered the cost-efficiency analysis for freestanding product classes to be representative for built-in product classes as well. Stakeholder comments regarding the impacts of increasing efficiency of built-in products are discussed briefly below.

Sub Zero commented that built-ins use more energy than freestanding units due to inherent design differences, and the overall difference in efficiency is between 5% and 15% depending on model and configuration. Sub Zero noted that DOE established separate product classes for built-in MREFs to account for unique consumer utility that built-in designs provide. Sub Zero stated that credits for built-ins are currently included in the standards for refrigerators and combination-cooler MREFs, but in the interest of achieving a successful outcome in the working group negotiations[c], the industry did not request a credit for built-in coolers; however, Sub Zero stated that it was understood that built-in coolers would need credits in any subsequent round of standards and therefore separate built-in product classes were recommended by ASRAC to permit different future standards levels for free-standing and built-in coolers. (Sub Zero, No. 8, pp. 1-2)

ASAP commented that there are both freestanding and built-in coolers across the range of volumes that consume significantly less energy than minimally compliant models, and the most efficient product is a built-in cooler, which consumes 54% less energy than the standard. (ASAP, No. 4, p. 1)

DOE performed an assessment of the range of efficiencies available for built-in cooler product classes to compare these to the corresponding freestanding product classes. Based on current market availability, built-in and freestanding product classes appear to have similar potential for efficiency improvement relative to the current energy conservation standard. This is depicted in Figure 5.2.1 below, with efficiency curves of 0%, 10%, 20%, and 30% energy use reduction below the current energy conservation standard shown for reference. Additionally, while certain freestanding products may not have the same design restrictions as built-in coolers, DOE observed that many freestanding coolers available on the market are designed for optional built-in installation, and therefore have similar designs (*e.g.*, the same outer dimension and airflow pathway constraints). While DOE analyzed only freestanding product classes for this preliminary engineering analysis, DOE relied on freestanding models with optional built-in installation as the basis of this analysis and expects that the resulting efficiency levels, design options, and costs are also applicable to the corresponding built-in product classes.

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[c] In its previous rulemaking, DOE established a working group through the Appliance Standards and Rulemaking Federal Advisory Committee ("ASRAC") to discuss and reach consensus recommendations on the scope of coverage, definitions, test procedures, and energy conservation standards for MREFs. *See* 81 FR 46767, 46770 (July 18, 2016).

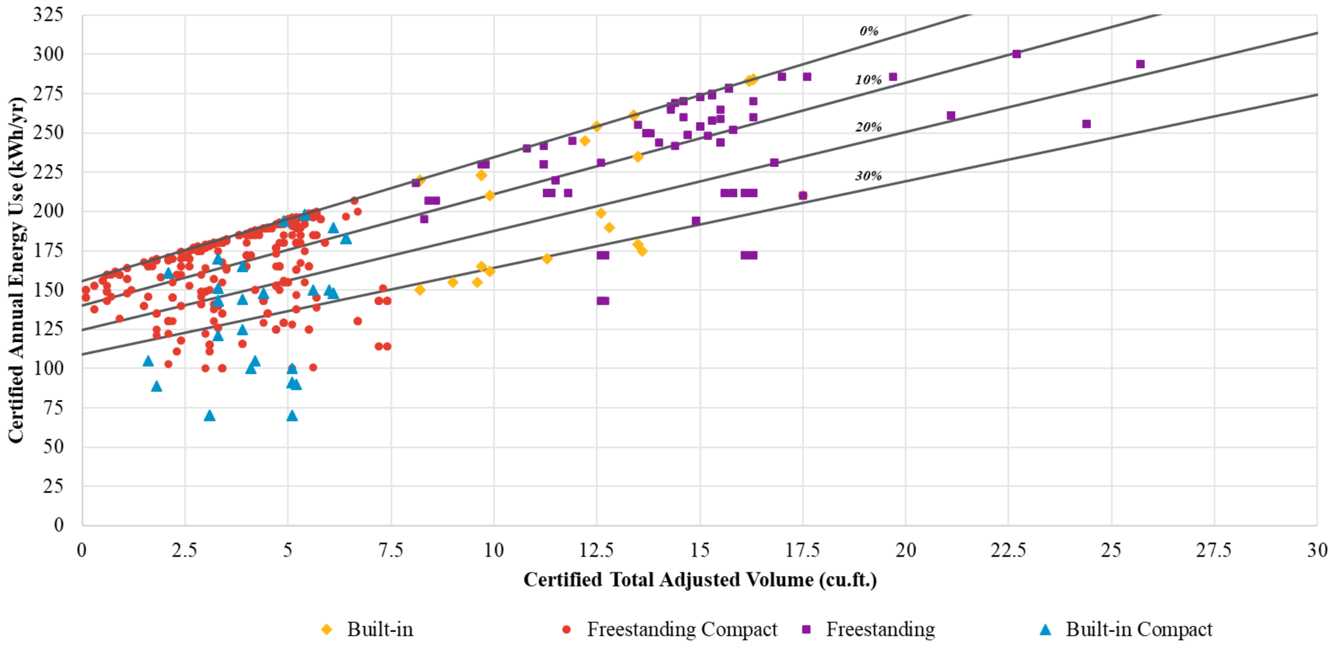

Figure 5.2.1 Cooler Models in DOE's CCMS Database

5.3 METHODOLOGY OVERVIEW

DOE relied on multiple sources of information for this engineering analysis. These sources include DOE's CCMS product energy use ratings, product teardowns, and product energy modeling.

5.3.1 Product Teardowns

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. DOE performed physical teardown analysis on MREFs from a range of manufacturers. The teardown methodology is explained in the following sections.

5.3.1.1 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.

Within each analyzed product class, as discussed in section 5.2, DOE selected representative units as the basis for the analysis based on the criteria outlined above. In addition, because MREFs are offered in a range of volumes, DOE selected units representing the most common adjusted volume(s) within a product class or adjusted volumes representative of the overall range available, based on models listed in DOE's CCMS database. These units ranged from 3.1 cubic feet (ft^3) to 15.3 ft^3 in adjusted volume and from baseline (0%) to 49% better than baseline efficiency.

Table 5.3.1 Adjusted Volumes and Efficiency of Teardown Unit Selections

Product Class	Adjusted volume (ft^3)	Efficiency Range (% Better than Baseline) of Selected Units
Cooler-FC	3.1 and 5.1	0%-49%
Cooler-F	15.3	0%-28%
C-13A	5.1	0%

5.3.1.2 Generation of Bill of Materials

The end result of each teardown is a structured 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[d] ("AMM"). Past price quotes are indexed using applicable Bureau of Labor Statistics producer price index tables as well as AMM monthly data. DOE regularly updates historical cost data to present-day prices using indices from resources such as MEPS Intl.[e], PolymerUpdate[f], the U.S. geologic survey ("USGS")[g], and the Bureau of Labor Statistics ("BLS")[h].

5.3.2 Manufacturing Cost Assessment

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 5.3.1 shows the three major steps in generating the manufacturing cost.

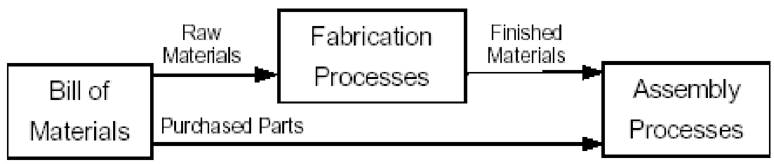

Figure 5.3.1 Manufacturing Cost Assessment Stages

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.

Following the development of a detailed BOM, the major manufacturing processes were identified and modeled. Some of these processes are listed in Table 5.3.2.

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

[e] For more information on MEPS Intl, please visit: *www.meps.co.uk/*

[f] For more information on PolymerUpdate, please visit: *www.polymerupdate.com*

[g] For more information on the USGS metal price statistics, please visit *www.usgs.gov/centers/nmic/commodity-statistics-and-information*

[h] For more information on the BLS producer price indices, please visit: *www.bls.gov/ppi/*

Table 5.3.2 Major Manufacturing Processes

Fabrication	Finishing	Assembly/Joining	Quality Control
Fixturing Stamping/Pressing Turret Punch Tube Forming Brake Forming Cutting & Shearing Insulating & Insulation Injection Tube/Wire Bending Brazing Vacuum Forming Blow Molding Injection Molding	Washing Painting 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, DOE estimated labor costs 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.

DOE noted and developed cost estimates for design options used in units subject to teardown. 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.

5.3.2.2 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. The equipment, tooling, and building depreciation costs are modeled as a "green-field" site; *i.e.*, a new manufacturing plant with all new equipment.

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.

5.3.2.3 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. DOE has confirmed its cost model assumptions over multiple rulemakings through direct observation of manufacturing plants, discussions with manufacturers and OEMs, reviews of current Bureau of Labor Statistics data, *etc*. To ensure that the best assumptions are used to develop final product cost estimates, DOE seeks feedback from manufacturers on all significant inputs to the analysis, such as raw material prices and purchased part costs (*e.g.*, compressors, motors, and vacuum-insulated panels (“VIPs”)).

5.4 COOLERS EFFICIENCY ANALYSIS

DOE developed representative efficiency levels for analysis using certified annual energy use data as well as modeled data to estimate performance beyond the efficiencies observed in the teardown units. Each efficiency level represents a percent energy reduction relative to the baseline.

In the December 2020 Early Assessment RFI, DOE sought feedback on technology options which may lead to improvements in MREF efficiencies. 85 FR 78964, 78966.

NEEA commented that there are a number of technologies available to improve MREF efficiency and encouraged DOE to consider the nine technologies in Table IV.3 of DOE's October 2016 Direct Final Rule based on an assumption that many of these technologies are employed in today's market considering the range of efficiency observed. (NEEA, No. 7, p. 2) NEEA further commented that the max-tech level considered in the analysis supporting the October 2016 Direct Final Rule is available on the market and therefore no longer represents the max-tech. NEEA encouraged DOE to consider efficiency levels beyond the max-tech considered for the October 2016 Direct Final Rule. (NEEA, No. 7, pp. 5-6)

GEA commented that no innovative technology has become available on the market since the last standards rulemaking for MREFs. (GEA, No. 6, p. 1)

In this efficiency analysis, DOE considered a variety of design options available in MREFs today to achieve incrementally higher levels of efficiency. DOE identified design options based on the entire set of technology options identified in chapter 3 of this TSD (including those technologies identified in NEEA's comment) and the screening criteria discussed in chapter 4 of this TSD. While not all technologies are currently in use in MREFs on the market, DOE considers in the engineering analysis any design options that meet the specific screening criteria. Any design options identified but not directly considered in the efficiency analysis are discussed in section 5.5.2 of this chapter.

AHAM commented that there is no new technology that would allow for significant per-unit reduction in energy consumption, but rather, any changes to the standard would require small improvements through modifications of components, adding insulation, changing controls, *etc*. AHAM stated that manufacturers must balance cost, functional performance, and energy consumption, and that the balance varies by model leading manufacturers to select different technology mixes by product platform. AHAM stated that as a rule, manufacturers make component changes first, and only if this is not sufficient to reach the necessary levels of efficiency do they make design changes. AHAM explained this is because the more radical or comprehensive the design change, the more likely that retooling is necessary and, thus, the greater the product cost and the investment. (AHAM, No. 3, pp. 2-3)

DOE understands that the design pathways manufacturers would choose to achieve higher efficiencies can vary among manufacturers and even among product lines from the same manufacturer. To determine cost-efficiency relationships that are representative of the overall market, DOE bases its analysis on common product volumes and configurations, as discussed in section 5.3.1.1 of this chapter. In addition to the per-unit MPCs determined as part of the engineering analysis, DOE would consider conversion costs associated with significant design changes as part of the manufacturer impact analysis conducted as part of the analysis supporting any subsequent notice of proposed rulemaking ("NOPR").

5.4.1 Baseline Efficiency Levels

DOE selected baseline units as the reference points for all of the analyzed product classes. DOE then determined efficiency and cost changes resulting from the use of energy-saving design options incorporated at higher efficiency levels. The baseline unit in each product class represents the basic characteristics of products in that class. A baseline unit is a unit that just meets current required energy conservation standards and provides basic consumer utility (*i.e.*, 0% better than the current standards).

The baseline energy use equations used in this preliminary analysis are shown in Table 5.4.1 (including the baseline for the C-13A product class). The definitions for adjusted volume are based on testing according to the current test procedure.

Table 5.4.1 Baseline Energy Use Equations

Product Class	Equations for Maximum Energy Use (kWh/yr)
Freestanding compact coolers	7.88AV + 155.8
Freestanding coolers	7.88AV + 155.8
C-13A. Compact cooler with all-refrigerator—automatic defrost	5.93AV + 193.7

AV= adjusted volume in cubic feet.

5.4.2 Incremental Efficiency Levels

DOE established five incremental efficiency levels ("ELs") beyond the baseline for each of the three analyzed cooler configurations (*i.e.*, two freestanding compact cooler volumes and one freestanding cooler volume). The first two efficiency levels beyond the baseline, EL1 and EL2, generally represent the reduced energy consumption of units minimally compliant with ENERGY STAR requirements.

As discussed in chapter 3 of this TSD, on August 5, 2021, the ENERGY STAR program established new criteria for energy efficient MREFs. These criteria are reproduced in Table 5.4.2 below. The ENERGY STAR criteria are established only for coolers and vary by product class. EL1 and EL2 in DOE's preliminary analysis span the 10-30% efficiency range indicated by ENERGY STAR criteria.

Table 5.4.2 ENERGY STAR Criteria for MREFs

Product Class	Equations for Maximum Energy Use (kWh/yr)	% Less Energy
Freestanding compact coolers	6.30AV + 124.6	20%
Freestanding coolers	7.09AV + 140.2	10%
Built-in compact coolers	5.52AV + 109.1	30%

Product Class	Equations for Maximum Energy Use (kWh/yr)	% Less Energy
Built-in coolers	5.52AV + 109.1	30%

AV= adjusted volume in cubic feet.

EL3 approximately corresponds to the maximum available efficiency on the market based on CCMS database ratings. For EL3, DOE conducted teardowns on units near the maximum available efficiency.

EL4 represents an additional level of energy savings associated with the incorporation of more expensive high-efficiency components.

EL5 for all analyzed product classes is the maximum technology ("max-tech") level based on DOE energy modeling using all applicable design options, as discussed further in section 0.

The efficiency levels analyzed beyond the baseline are shown in Table 5.4.3 below.

Table 5.4.3 Incremental Efficiency Levels for Analyzed Coolers (% Energy Use Less than Baseline)

Product Class (AV, ft^3)	Cooler-FC (3.1)	Cooler-FC (5.1)	Cooler-F (15.3)
EL 1	20% †	20% †	10% †
EL 2	30% ‡	30% ‡	20%
EL 3	45%	49%	30% ‡
EL 4	50%	50%	35%
EL 5 – Max Tech	51%	52%	39%

† Minimally compliant with ENERGY STAR requirements for freestanding products.
‡ Minimally compliant with ENERGY STAR requirements for built-in products.

5.4.3 Maximum Technology Level

DOE defines a max-tech level to represent the maximum possible efficiency if all available design options are incorporated into a product. In many cases, the max-tech level is not commercially available because it is not economically feasible.

DOE determined max-tech levels using energy modeling based on the use of all design options applicable for the analyzed product classes. While these product configurations have not likely been tested as prototypes, all of the individual design options have been incorporated in available refrigeration products as observed during product teardowns. The max-tech efficiencies and corresponding design options for the analyzed product classes are presented in Table 5.4.4. Note that the design options indicated in the table only represent those design options included in the analysis to incrementally reduce energy use relative to the baseline efficiency level. If, for example, the baseline unit for a product class was observed to already include isobutane refrigerant (as observed for the analyzed coolers), that is not included in the table as a design option to improve efficiency at the max-tech level.

Table 5.4.4 Max-Tech Levels and Design Options

Product Class (AV)	% Less Energy (Than Baseline)	Design Options Used									
		Variable Speed Compressor	Tube-and-Fin Evaporator	Additional Evaporator	Tube-and-Fin Condenser	Hotwall Condenser	Static Condenser	Triple-Pane Glass Door	Thicker Insulation	Partial VIP	Fan Motor Improvements
FC (3.1)	51%	✓	✓		✓			✓	✓	✓	✓
FC (5.1)	52%	✓	✓		✓	✓		✓	✓	✓	✓
F (15.3)	39%	✓	✓	✓			✓	✓	✓	✓	✓

5.4.4 Energy Modeling

DOE relied on energy modeling to estimate the energy savings associated with implementing design options beyond those observed during product teardowns. The products selected for reverse engineering provided the basis for key characteristics to input into the energy model – cabinet construction, insulation thicknesses, *etc*.

Similar to the 2021 RFs Preliminary Analysis, DOE carried out energy modeling during this preliminary analysis using a version of the Environmental Protection Agency's Refrigerator Analysis ("ERA") program, earlier versions of which have been used in previous refrigerator, refrigerator-freezer, and freezer energy conservation standards rulemakings. ERA is a steady-state energy model that calculates heat leakage into a cabinet and determines the energy needed by the refrigeration system to maintain the interior temperatures as specified by the user. Total energy used includes the energy from the compressor, fan motors, defrost heater, electronic control, and anti-sweat heaters, if applicable.

However, DOE did not rely only on ERA to directly estimate product performance. Compressor map information was not available for all compressors identified during unit teardowns. Accordingly, DOE could not ensure that ERA model results would be appropriate when incorporating these new components.

DOE instead used ERA as a tool to estimate the breakdown of energy use, by component, for each unit in the teardown analysis. ERA specifically allowed DOE to estimate the thermal load for each cabinet (including the glass door) to estimate the overall load on the refrigeration system. ERA inputs for glass doors include the door dimensions and U-factor. Similar to the analysis conducted in the October 2016 Direct Final Rule, DOE calculated door U-factors using the WINDOW and THERM software version 7.7 created by Lawrence Berkeley National Labs.[i] DOE then estimated the following component energy contributions to each unit's overall energy consumption: compressor, fan(s), and controls.

With the thermal load and component energy use distribution for each analyzed unit, DOE then estimated the reduction in energy consumption associated with implementing additional design options. For example, for improved compressor efficiencies, DOE calculated the expected energy use reduction based on performance data for high-efficiency single-stage and variable-speed compressors available on the market for use in refrigeration products. For design options affecting the cabinet thermal load, for example, improved glass doors, DOE used ERA to model the thermal load of the cabinet based on the modeled door U-factors. This reduces the overall load on the refrigeration system compared to the teardown unit, which would again reduce overall compressor energy use.

Details regarding the design options considered at each efficiency level are described in section 5.5 and the corresponding energy use reductions are provided in section 5.6.

5.5 COOLERS DESIGN OPTIONS

As described in section 5.3.1.1, DOE conducted teardowns that spanned the range of product efficiencies and features available on the market from multiple manufacturers for the most representative product classes and adjusted volumes. DOE relied on teardowns to investigate how product construction related to rated product performance. Specifically, the teardowns allowed DOE to identify design options currently used for improving efficiency and to develop corresponding MPCs for products at different efficiency levels.

After conducting the screening analysis described in chapter 4, DOE considered the remaining design options in the engineering analysis. Table 5.5.1 lists the design options DOE considered for each product class to improve performance from the baseline efficiency level to higher efficiency levels. As discussed in section 0, DOE observed that multiple baseline products already incorporate certain design options. For these product classes, those design options are not included in Table 5.5.1.

Table 5.5.1 Incremental Design Options* by Efficiency Level and Product Class

	Product Class (AV)		
Efficiency Level	**Freestanding Compact (3.1)**	**Freestanding Compact (5.1)**	**Freestanding (15.3)**
EL1	• High-efficiency single-stage compressor • Argon glass pack	• High-efficiency single-stage compressor • Thicker insulation • BLDC condenser fan • Argon glass pack	• High-efficiency single-stage compressor • Thicker insulation • Hotwall condenser addition

[i] WINDOW and THERM downloads and documentation are available online at windows.lbl.gov/software/window and windows.lbl.gov/software/therm. (Last accessed on October 5, 2021).

	Product Class (AV)		
Efficiency Level	**Freestanding Compact (3.1)**	**Freestanding Compact (5.1)**	**Freestanding (15.3)**
EL2	• Tube-and-fin condenser • Tube-and-fin evaporator • Most efficient single-stage compressor	• Tube-and-fin evaporator	• Soft-coat glass pack
EL3	• Thicker insulation • More efficient evaporator fan motor • Triple-pane glass pack**	• Most efficient single-stage compressor • Hotwall condenser addition • Soft-coat glass pack	• Variable-speed compressor • Thicker insulation • Static condenser • Additional evaporator • Most efficient evaporator fan motor
EL4	• Variable-speed compressor •	• Variable-speed compressor • Triple-pane glass pack**	• Triple-pane glass pack**
EL5	• Partial VIP	• Partial VIP	• Partial VIP

*Design options are cumulative between efficiency levels (except for component replacements)
** Triple-pane glass pack consists of soft-coated low-E glass and argon gas fill (with a reduced gap size to maintain door thickness)

In general, DOE relied on design options observed in the directly analyzed models to determine design options from baseline through EL3. Beyond that, DOE introduced any remaining design options at EL4, except for VIPs, which represented the incremental change at EL5 for each analyzed product.

The following sections describe how DOE considered each of the design options that passed the screening analysis (as described in chapter 4 of this TSD) during the engineering analysis. Section 5.5.1 describes how DOE incorporated the analyzed design options (as included in Table 5.5.1) into the cost-efficiency curves. Section 5.5.2 describes design options that meet the screening criteria, but were not directly analyzed in this engineering analysis. Chapter 3 of this TSD includes background descriptions for each of the technologies.

5.5.1 Component Efficiency Improvements

The design options considered for component efficiency improvements in this engineering analysis are shown in Table 5.5.2.

Table 5.5.2 Design Options Utilized in Engineering Analysis

Insulation	**Evaporator**
Insulation type	Increased surface area *or* additional evaporator
Increased insulation thickness	Evaporator type
Vacuum-insulated panels	**Fans and Fan Motor**
Compressor	Evaporator fan motor improvements
Improved compressor efficiency	Condenser fan motor improvements
Variable-speed compressors	**Glass Door**
Condenser	Inert gas fill
Increased surface area	Low-E glass
Condenser type	Additional (third) pane

Increased Insulation Thickness

During the October 2016 Direct Final Rule analysis, DOE collected information from manufacturers regarding insulation thickness increases, which may be very limited for many product classes. Greater insulation thickness would typically result in either decreased interior volumes, increased exterior dimensions, or some combination of both. Reduction in internal volume is undesirable because this is a key selling feature. Additionally, increased exterior dimensions are undesirable because many units are installed in fixed-dimension locations (*e.g.*, under a counter in a kitchen or in a built-in cabinet enclosure). Thus, DOE only considered modest thickness increases in the previous rulemaking analysis. See chapter 5 of the October 2016 Direct Final Rule TSD.

In this preliminary analysis, DOE considered increased insulation thickness for MREFs only where it was directly observed in product teardowns. This ensures that the use of increased insulation is possible for MREF models already on the market. As discussed in section 5.2.1 of this chapter, while DOE analyzed only freestanding product classes for this preliminary engineering analysis, DOE relied on freestanding models with optional built-in installation as the basis of this analysis. Accordingly, these models maintained outer dimensions necessary to accommodate built-in installations.

DOE calculated costs associated with insulation thickness increases using the manufacturing cost model. DOE considered costs of increased foam as well as costs associated with other components that would scale with different insulation thickness.

DOE acknowledges that changes to insulation thickness require investment in manufacturing facilities and product redesign. Although this engineering analysis estimates manufacturer production costs on a per-product basis, DOE considers such investments and the corresponding manufacturer impacts as part of any subsequent NOPR analysis, should DOE propose any amended energy conservation standards for MREFs.

Improved PU Insulation Resistivity (Insulation Type)

As discussed in chapter 3 of this TSD, DOE is aware that different blowing agents may improve product efficiency by increasing the thermal resistance of the insulation, thereby decreasing the thermal load on the product. Manufacturers have introduced hydrofluoro-olefin ("HFO") low-

GWP blowing agents with claims of improved efficiencies and thermal resistivities from 2 percent to 11 percent compared to HFC-245fa blowing agents.[1,2] A number of manufacturers, including Whirlpool, have already incorporated these higher efficiency blowing agents into their refrigerators and freezers.[3,4] Therefore, those manufacturers would not rely on upgrading foam insulation to using HFO blowing agents as a design change to improve product efficiencies beyond the baseline. DOE is unaware of commercially-viable insulation blowing agents which can further improve efficiency over HFOs (including CO_2).

During the teardown analysis, DOE was not able to identify the blowing agent type used for each unit's PU foam insulation. For this reason, and because DOE is aware that manufacturers already use HFO blowing agents in PU foam for many products, DOE assumed that all teardown units already incorporated HFO blowing agents. Incorporating this design option from the baseline efficiency also avoids potentially overestimating the possible efficiency improvements from introducing improved blowing agents. Hence, HFO blowing agents were incorporated at all efficiency levels rather than being considered as an incremental efficiency improvement between efficiency levels.

Vacuum-Insulated Panels

VIPs increase efficiency by significantly increasing the thermal resistivity of the cabinet walls, and therefore decreasing heat penetration into the cabinet. The vast majority of MREFs have glass doors for the display utility, which generally results in more heat penetration through the door than through the walls of the cabinet. Because the glass door is usually the major heat transfer pathway and because the higher compartment temperature of MREFs results in a lower temperature differential between the walls and the ambient as compared to other refrigeration products, DOE expects VIPs to be the least cost-effective design option for MREFs. In addition to the per-unit costs, DOE recognizes that implementing VIPs would also lead to significant conversion costs for manufacturers. Hence, DOE only modeled the installation of VIPs at the max-tech efficiency level.

In response to the December 2020 Early Assessment RFI, AHAM stated that VIPs are an expensive technology option to improve efficiency, but these cannot be used for all model types. (AHAM, No. 3, p. 3)

DOE understands that full-sized VIPs may not be a design option available for certain cabinet designs (*e.g.*, hotwall or coldwall heat exchangers) and thus DOE assumed that only partial VIPs would be implemented in MREFs. Although DOE did not observe VIPs in use in any directly analyzed MREFs, DOE relied on characteristics of how VIPs are installed in refrigerators, refrigerator-freezers, and freezers to estimate the cost and efficiency impacts of implementing VIPs for max-tech coolers.

Chapter 3 of this TSD discusses the possible ranges of VIP conductivities based on construction. For this engineering analysis, DOE assumed a mid-panel conductivity of 3.1 mW/m-˚C. In contrast, the conductivity of high-efficiency PU foam is approximately 18 mW/m-˚C. As discussed in chapter 3 of this TSD, lower thermal conductivities have been shown for VIPs. However, the availability of such improved VIPs for MREFs is unclear, so DOE did not consider any further incremental VIP improvements in this engineering analysis.

DOE is aware that the effective conductivity of a surface incorporating a VIP is not equal to the conductivity of the VIP panel itself. From its 2021 RFs Preliminary Analysis, DOE observed that VIPs are encased in PU foam to hold the panel in place, including a border of PU foam surrounding the VIP (*i.e.*, the VIP did not extend to the corners of the cabinet surface). DOE assumed that implementing a VIP in an MREF would require similar foam boundaries to hold the VIP in place and to provide structural support for the cabinet.

To estimate the thermal performance of composite walls including VIPs, DOE used composite wall average thermal resistivities. The composite wall resistivity, R_w, was calculated as follows in Eq. 5.1:

Eq. 5.1

$$R_w = \frac{(R_{VIP}t_{VIP} + R_{PU}t_{PU})}{t_{VIP} + t_{PU}}$$

Where R_{VIP} and R_{PU} are the thermal resistivities of the VIP and the PU foam, and t_{VIP} and t_{PU} are the thicknesses of the VIP and PU foam layers. The thermal resistivity, R, for a material is the inverse of the conductivity. Consistent with the 2021 RFs Preliminary Analysis, DOE also used a scaling factor of 50% to account for the actual vs. expected performance of VIPs. For this analysis, DOE assumed that the effective R value for a surface would be an average of the calculated R_w and the R value of PU foam, thereby reducing the effectiveness of the VIP compared to its calculated resistivity.

The quantity of VIPs that can be added to the cabinet is limited by structural design requirements. To account for the type and configuration of installation observed during the physical teardown (*i.e.*, foam support on the surface in which the VIP is installed), DOE also limited the use of VIPs to approximately 50% of the cabinet surface area and all door panels. This is consistent with the approach used in the 2021 RFs Preliminary Analysis.

DOE used ERA to estimate the cabinet thermal load reduction achievable by using VIPs at max-tech efficiencies. DOE used the expected thermal resistivity for each surface with a VIP as described above. From the ERA results, DOE estimated that incorporating VIPs would reduce cabinet wall heat loads by only 3% to 8%, depending on product class. Standard-size coolers, for example, benefit more from VIPs.

DOE used the following cost estimates and assumptions to estimate the increase in MPC associated with incorporating VIPs:

- Average applied panel cost per square foot based on estimates derived from past supplier surveys updated to today's prices;
- Added glue required to adhere the panel to cabinet surfaces; and
- Cost savings associated with displaced PU foam based on VIP volume.

Improved Compressor Efficiency

DOE considered the substitution of higher efficiency compressors as a design option change for all analyzed product classes. DOE estimated performance associated with the highest efficiency single-speed compressor available before assuming a switch to a variable-speed compressor.

DOE acquired compressor performance data from manufacturer catalogs and specification sheets. Where teardown analyses were conducted and step improvements in compressor efficiency were observed, DOE modeled the performance of the compressor present in the unit. The range of compressor energy efficiency ratios ("EERs") in teardown samples was approximately 4.4 Btu/Wh to 5.7 Btu/Wh.[j] To determine whether further improvements could be made to the teardown model compressors, DOE compiled publicly available compressor performance data from compressor manufacturers and distributors. The range of available compressor efficiencies found in DOE's analysis is illustrated in Figure 5.5.1 below.

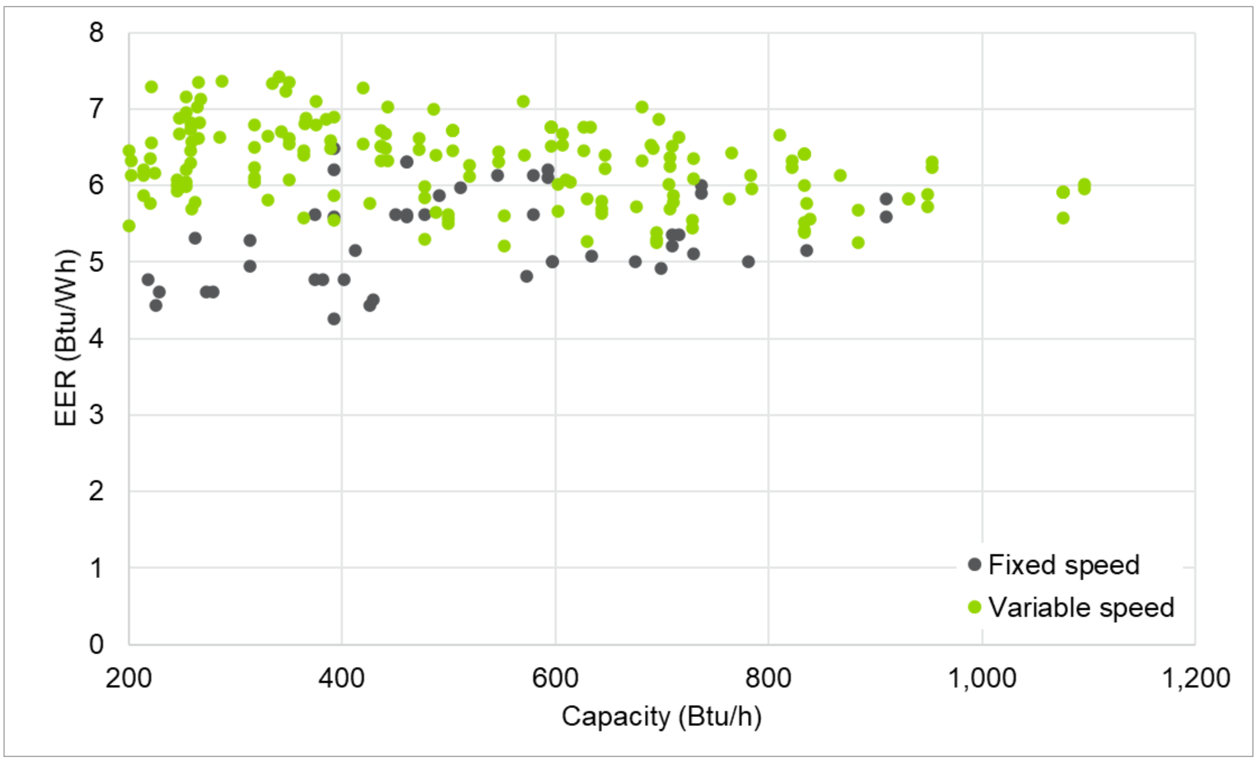

Figure 5.5.1 Efficiency Curve for R-600a Compressors (LBP)

These capacity and efficiency ratings are presented at LBP rating conditions for comparability because other ratings are often not available for compressors without publicly available performance maps. However, because cooler compartments are warmer than fresh food or freezer compartments, the LBP rating condition is not representative of actual operating performance for coolers (although it can be indicative of the relative efficiencies of

[j] These capacities and efficiencies correspond to ASHRAE low back pressure ("LBP") rating conditions.

compressors). At the higher evaporator temperatures found in cooler compartments, capacity and efficiency is substantially higher. DOE used detailed compressor performance maps and correlations to estimate the cooling capacity and efficiency of each compressor running at more representative refrigerant temperatures: 30 °F suction dew point temperature and 110 °F discharge dew point temperature. Using these methods, the estimated compressor efficiencies at MREF temperatures ranged from 10.18 Btu/Wh to 15.75 Btu/Wh. Based on these factors, DOE determined that the single-speed compressors observed in the higher efficiency teardown models typically represented the best-available single-speed compressors at the relevant capacities.

DOE based compressor prices for R-600a compressors on 1) estimates which were derived from past supplier surveys that were updated to current prices, 2) current market reviews and vendor cost estimates, and 3) industry experience.

Variable-Speed Compressor

During physical teardowns, DOE observed a variable-speed compressor ("VSC") in one freestanding standard-sized cooler. DOE obtained compressor performance data from manufacturer catalogs and specification sheets. The EERs for VSCs are typically consistent with the EERs of the highest available efficiency single-speed compressors, as shown in Figure 5.5.1. However, the efficiency gains associated with a VSC can be associated with fewer cycling losses.

DOE estimated VSC performance by using performance maps provided in compressor manufacturer product literature. DOE modeled the performance of the VSC operating at a speed which optimized the efficiency of the unit by balancing the compressor energy use with that of the other cycling components. While VSCs may save energy by operating at a lower speed state with fewer cycling losses, incorporating VSCs also increases energy consumption associated with other product components due to longer cycle runtimes.

Due to the longer compressor runtime, fans operate for a longer duration compared to single-speed compressor refrigeration systems. This fan energy use can negate much of the reduction in compressor energy use, but the BLDC fan motors used in conjunction with a VSC are efficient and allow the fans to operate at a lower speed and power draw. In this analysis, DOE used the speed of the VSC to estimate the variable frequency drive ("VFD") output frequency and, as a result, the corresponding BLDC fan motor speed and power scaling factor.

DOE based estimates of the cost increase for switching to VSCs from information gathered from the physical teardown units, estimates based on past supplier surveys that were updated to today's prices, current market reviews, and industry experience. This cost increase is driven primarily by the controls required for a VFD/inverter. DOE used these cost increases in the analysis for all product classes, as the components associated with the conversion to VSCs do not scale with capacity of the compressor.

Improved Evaporator

For heat exchangers, a larger effective surface area or more effective heat transfer allows the heat transfer to occur more efficiently. There are two ways in which the surface area of a heat exchanger can be increased: 1) by increasing the dimensions of the heat exchanger (for example, through the addition of an extra evaporator in series), or 2) by changing the form factor of the heat exchanger to increase the points of contact for heat transfer. In physical teardowns, DOE generally observed both types of improvements at higher efficiency levels.

As discussed in chapter 3 of this TSD, there are three main types of evaporators: coldwall, roll-bond, and tube-and-fin. In this preliminary analysis, DOE modeled the evaporator design based on observations from teardown units. For example, roll-bond evaporators were found in the baseline 3 ft^3 compact coolers around, whereas a coldwall evaporator was found in baseline 5 ft^3 compact coolers. Additionally, tube-and-fin evaporators were observed in higher efficiency teardown across all product configurations. DOE only considered increases in evaporator surface area or additional evaporators based on designs implemented in teardown models. This approach ensures that the considered evaporator improvements are consistent with the cabinet size limitations for each product volume.

DOE estimated the costs associated with improved evaporators by directly inputting the specifications of heat exchangers observed in teardown units to DOE's cost model.

Improved Condenser

Similar to evaporators, the effectiveness of a condenser can be improved by either modifying the dimensions, adding an extra condenser in series, or changing the form factor. DOE observed the addition of extra condenser piping and changes in form factor in teardowns.

As discussed in chapter 3 of this TSD, there are three main types of condensers: hotwall condensers, static condensers, and tube-and-fin condensers. Similar to evaporators, in this preliminary analysis DOE considered the condenser designs observed in teardown units. All three types of condensers were found in teardowns. In certain models, DOE observed hotwall condensers added in series to tube-and-fin condensers to effectively increase the heat transfer surface area. DOE considered this to be a design option to improve condenser effectiveness at the efficiency levels where this was observed.

DOE estimated the costs associated with improved condensers by directly inputting the specifications of heat exchangers observed in teardown units to DOE's cost model.

Improved Glass Doors

Chapter 3 of this TSD discusses several approaches to improving the efficiency of glass doors. These include low-emissivity ("low-E") glass coatings, inert gas fills, additional panes, and improved frame design. As discussed in chapter 3 of this TSD, hard-coat low-E glass is less efficient (but less expensive) compared to soft-coat low-E glass. Based on a review of MREF product literature, DOE found that products rated at or near baseline efficiency were often marketed as having low-E glass. DOE was unable to determine the emissivity of the glass panes in its teardowns. To avoid overestimating the potential efficiency improvements associated with low-E glass, DOE assumed that all efficiency levels would be utilizing at least hard-coat low-E glass. Modeling suggests that a transition to soft-coat low-E glass could occur near the maximum available market efficiencies for coolers. DOE is seeking additional information from stakeholders about the use of low-E glass in refrigeration products.

Similarly, DOE was unable to identify the gas fill in the teardown samples absent information in marketing materials. Based on a review of current product literature, DOE did not find krypton gas being applicable for residential appliances and hence did not consider it as an option for this preliminary analysis. DOE reviewed product literature to determine that baseline compact coolers likely use air fills, so DOE considered argon fill as a design option to improve the efficiency of compact glass doors. By contrast, DOE identified argon fills in marketing materials for standard-sized coolers rated near baseline and therefore only considered the number of glass panes and low-E coatings as design improvements for that product class.

DOE observed a triple-pane glass pack in one of its teardown samples. The design of the triple-pane glass pack at higher efficiency levels was based on this sample.

Brushless DC ("BLDC") Fan Motors

BLDC fan motors are more efficient than the shaded pole motors ("SPM") which, historically were often used in baseline refrigeration products. However, during DOE's teardown analysis, DOE observed BLDC fan motors in each baseline sample torn down except for the baseline 5 ft^3 freestanding cooler, where an SPM condenser fan motor was present.

For the baseline model with an SPM condenser fan motor, DOE modeled the conversion to BLDC based on the BLDC fan motor present in the higher efficiency teardown model for that product configuration.

5.5.2 Design Options Not Specifically Considered

While many of the technology options identified in chapter 3 of this TSD may produce energy savings in certain real-world situations, DOE did not further consider them in this analysis because 1) there was not sufficient information available on the specific efficiency gains, 2) these options were not observed during physical teardowns, 3) these options are not required for major efficiency improvements, or 4) the DOE test procedure would not capture those potential improvements. These design options are listed below and discussed more in detail in the following subsections.

- Refrigerant anti-sweat heating
- Electric anti-sweat heater sizing and controls
- Microchannel condensers
- Improved expansion valve
- Tandem evaporator systems
- Fan blade improvements
- Off-cycle defrost, adaptive defrost or reduced energy for automatic defrost
- Gas-filled insulation panels
- Electronic temperature control
- Alternative refrigerants

- Glass door frame design
- Air distribution controls

Refrigerant and Electric Anti-Sweat Heating

According to DOE's reverse engineering work and previous discussion with manufacturers, refrigerant-line heat is what is typically used in baseline refrigerators, refrigerator-freezers, and freezers with anti-sweat heating. DOE's teardown analysis showed that not all MREFs come equipped with anti-sweat heating. Cooler compartments typically operate at higher temperatures than fresh food or freezer compartments, and therefore condensate formation is less likely to occur on MREFs. Because anti-sweat heat may not be universally incorporated into all MREFs, DOE has not factored this design option into the preliminary engineering analysis.

Variable electric anti-sweat heater controls adjust the time-average wattage of an electric anti-sweat heater based on ambient temperature and humidity conditions so that all surfaces are just above the ambient dew point. As discussed above, not all MREFs implement anti-sweat heat due to their higher compartment temperatures. When implemented, DOE expects that manufacturers would be more likely to use refrigerant anti-sweat rather than electric; therefore, better sizing and control of electric anti-sweat heaters is generally not relevant. Hence, DOE has eliminated this option from further consideration in the preliminary engineering analysis.

Microchannel Condensers

DOE did not observe microchannel condensers in any of the products in the teardown analysis. As discussed in chapter 3, microchannel condensers may allow for refrigerant charge reductions and improved heat transfer, but known drawbacks to these designs include irregular refrigerant distribution and greater pressure drops on the refrigerant side and air side. Therefore, the benefits of microchannel condensers may not include efficiency improvements. Hence, DOE did not consider microchannel condensers as a design option in the cost-efficiency analysis.

Improved Expansion Valve

Refrigeration products exclusively use capillary tubes for refrigerant flow metering. These tubes are inexpensive and allow for low-cost fabrication of suction line heat exchangers by brazing the capillary to the suction line. Automatic, adjustable thermostatic or electronic expansion valves are available, but they generally are oversized for household refrigeration products. Furthermore, it is unclear whether there is any potential for energy savings using alternative expansion devices. The DOE test procedure is conducted with a single set of standardized temperatures for the ambient air (90 °F) and the refrigerated compartments. An automatic valve could provide optimum performance for a wider range of operating conditions, but such improvement is not reflected in current energy testing. Hence, DOE has not factored this into the cost-efficiency analysis.

Fan Blade Improvements

MREF fan blades use an axial design. They are typically injection molded plastic with a three-dimensional shape for improved performance as compared with older stamped sheet metal designs. One source of inefficiency for axial fans lies in their tendency to throw air outward, necessitating a shroud to collect and redirect airflow along the axis as intended.

The Pax Group™ has developed a fan (PAX fan) that employs streamlined blades with patented geometrical shapes derived from a naturalistic design approach, providing better airflow direction and improved efficiency. Tests performed when replacing existing motor combinations with A.O. Smith motors and PAX fan blades show power input reductions in the range of roughly 10 percent to 35 percent.[k] It is not well understood how much of this benefit is associated with the fan blade and how much with the motor. Also, because the PAX fan is proprietary, the widespread use of the design is highly uncertain.

In response to the December 2020 Early Assessment RFI, AHAM commented that higher-efficiency fan blades can incur costs to implement but will not lead to significant energy savings. (AHAM, No. 3, p. 3)

There is in general little data available to quantify the energy benefit possible with improvement in fan blade design in today's refrigeration products. Fan performance is highly dependent on details of integration with the system: orifice geometry, tolerance of blade/orifice gap, match of system flow impedance to fan performance, *etc*. Hence, making credible estimates of energy savings potential through fan blade replacement requires testing fan blade swaps in baseline products. The cost of fabrication of improved fan blade geometries should be low, so most of the cost increase associated with this technology option would be associated with paying for the blade development and/or licensing fees. It is very difficult to predict what these costs would be unless specific vendors of high efficiency fan blades can be identified who provide complete information.

Similar to the 2021 RFs Preliminary Analysis, DOE has not included this design option as an expected change in this engineering analysis.

Off-Cycle Defrost, Adaptive Defrost, and Reduced Energy for Active Defrost

An adaptive defrost system adjusts the time interval between defrosts based on some indication of the need for defrost. A common indicator is the length of time required to complete the previous defrost. Other indicators could include the number of door openings or a measurement of ambient humidity. DOE considered this design option for its 2021 RFs Preliminary Analysis; however, adaptive defrost systems have limited potential to improve efficiency for coolers. From its test sample, DOE observed that off-cycling is the predominant method of defrosting for coolers. A heater does not typically need to be activated because the

[k] Belko, John. "Novel Fan Design Offers Energy Savings to Refrigeration Market," 2007. *A.O. Smith Electrical Products Company.*

evaporator temperature is higher in cooler compartments. As a result, the energy consumed during defrost operation would typically only be due to evaporator fans (if they stay on during the defrost sequence), and, unlike for refrigerators, refrigerator-freezers, and freezers, this results in defrosting drawing less power than steady-state operation. For these reasons, DOE did not model adaptive defrost as a design option to improve efficiency for coolers.

For any MREFs with active defrost, the defrost heat supplied can be more than required. Thus, energy savings could be achieved by reducing the defrost heat by either using smaller heaters, reducing the heater on-time, reducing the frequency of defrost, or a combination of these. DOE expects that manufacturers have already implemented passive (off-cycle) defrost as a more efficient and viable solution for MREFs, however. Hence, DOE has not factored this design option into this engineering analysis.

Gas-Filled Insulation Panels ("GFPs")

As discussed in chapter 3 of the TSD, DOE has not been able to identify suppliers of gas-filled panel products to the refrigeration industry. DOE also expects manufacturers would rely on VIPs rather than GFPs to improve insulation beyond the typical PU foam, as costs would be similar for GFPs and VIPs. For this reason, DOE has not incorporated GFPs in this engineering analysis.

Electronic Temperature Control

DOE has not identified any relevant information showing the energy benefit of electronic temperature control. Potential benefits of electronic control when operating with single-speed compressors are fine-tuning of the run times and fine-tuning of the cut-in and cut-out temperatures. While there may be potential for incremental improvement associated with such fine-tuning, the lack of data supporting claims for energy savings make it difficult to properly analyze this option. Additionally, electronic temperature controls were observed in each baseline configuration in DOE's sample set, so there would be no incremental improvement associated with this design option in this analysis.

Alternative Refrigerants

As mentioned in chapter 3 of this TSD, R-600a (isobutane) is used predominantly in Europe and Asia, and is increasingly used in the United States. R-600a also has the potential for higher efficiency than the R-134a refrigerant that is commonly used in U.S. refrigeration products.

In response to the December 2020 Early Assessment RFI, ASAP provided that alternative refrigerants represent a path to higher efficiency levels beyond the "max-tech" levels evaluated in the last rulemaking, and many coolers are now using R-600a refrigerant, as opposed to R-134a. ASAP indicated that R-600a may lead to efficiency improvements up to 6.5%. (ASAP, No. 4, p. 2)

In teardowns, DOE observed R-600a refrigerant in all but one unit. Based on a review of MREF product literature, DOE expects that the majority of vapor-compression MREFs sold in the U.S. today already utilize R-600a, and therefore there are limited models on the market that would benefit from a transition to R-600a. Hence, DOE did not consider alternative refrigerants as a broadly applicable design option to improve efficiency. In this preliminary analysis, each efficiency level represents a design utilizing R-600a refrigerant and, therefore, DOE did not consider a refrigerant change as an incremental design option to achieve higher efficiencies.

Glass Door Frame Design

As discussed in chapter 3 of this TSD, glass door frames represent a potential heat leak pathway for MREFs, depending on frame design. MREF door frames may be constructed with air gaps to act as thermal breakers to reduce heat leak and improve efficiency. For this engineering analysis, DOE conducted its cost-efficiency analysis on the door frames observed in the units torn down for analysis. While DOE observed different door frame designs, DOE was not able to determine the relative thermal resistance of the different designs. Accordingly, DOE did not directly consider improved door frame designs in this analysis, except as already accounted for in the performance of units directly analyzed.

Air Distribution Controls

Uniform air distribution within a refrigerated cabinet can improve efficiency by allowing the evaporator to operate at a slightly higher temperature. For this engineering analysis, DOE did not specifically consider improved air distribution controls as a design option expected to improve efficiency. However, DOE did analyze a design option change to forced-air evaporators at the higher efficiency levels for all analyzed product configurations. DOE expects that the airflow associated with a forced-air evaporator would already achieve any efficiency improvement that would be expected from improved air distribution controls.

5.6 COOLERS ANALYSIS AND RESULTS

DOE generated cost-efficiency curves for three different product configurations based on combinations of individual design options. This includes two representative volumes for freestanding compact coolers and one representative volume for freestanding coolers. DOE estimated the MPC associated with incorporating each design option as described in section 5.5. The overall incremental MPCs in 2020$ for each efficiency level beyond the baseline are presented in Table 5.6.1 below.

Table 5.6.1 Incremental MPC Results for Coolers

Product Class (AV, ft^3)	Cooler-FC (3.1)	Cooler-FC (5.1)	Cooler-F (15.3)
EL 1 (%—Cost)	20% – $5.59	20% – $6.36	10% – $16.55
EL 2 (%—Cost)	30% – $48.50	30% – $9.97	20% – $59.12
EL 3 (%—Cost)	45% – $113.98	49% – $34.36	30% – $106.02
EL 4 (%—Cost)	50% – $166.57	50% – $135.83	35% – $266.38
EL 5 – Max Tech (%—Cost)	51% – $184.43	52% – $155.07	39% – $324.37

5.7 COMBINATION COOLER REFRIGERATION PRODUCTS CONSIDERATION

As discussed in sections 5.1 and 5.2 of this chapter, DOE did not conduct a full engineering analysis on combination cooler refrigeration products as it did for coolers. Combination cooler refrigeration products represent a much smaller portion of the overall MREF market, and models available typically have unique configurations.

Combination cooler refrigeration products by definition are products that include a cooler compartment combined with refrigerated compartments that would otherwise meet DOE's definitions for refrigerators, refrigerator-freezers, or freezers. The other refrigerated compartments operate at temperatures lower than the cooler compartment and therefore are the primary driver for the energy consumed by combination cooler refrigeration products (*i.e.*, the refrigeration system must operate to accommodate the coldest compartment temperatures). With this product configuration, DOE determined that the engineering analysis for refrigerators, refrigerator-freezers, and freezers would provide an indication of the efficiency improvements possible (and corresponding costs) for combination cooler refrigeration products.

As discussed in section 5.1 of this chapter, DOE did conduct a teardown on one baseline model from product class C-13A. DOE used this to inform the baseline MPC for the product class to provide a basis for applying the 2021 RFs Preliminary Analysis results for compact refrigerators (*i.e.*, the corresponding non-combination product class). Additionally, DOE assigned additional incremental cost to represent an improved glass door at the efficiency level that otherwise accounted for VIPs from the 2021 RFs Preliminary Analysis.

For the other freestanding combination cooler refrigeration product classes currently in place (C-3A and C-9), DOE did not conduct product teardowns due to the lack of product availability and the low market share of those products. DOE did however construct example cost-efficiency curves showing the potential for efficiency improvement and corresponding cost, assuming combination cooler refrigeration products could follow the same design option pathways as determined in the 2021 RFs Preliminary Analysis for the corresponding non-combination product classes (product classes 3 and 9), with improved glass door costs applied at the efficiency level assuming a transition to VIPs.

Table 5.7.1 provides the cost-efficiency curves in 2020$ for the three considered product classes of combination cooler refrigeration products. As described, the efficiency and cost values were determined in the 2021 RFs Preliminary Analysis.

Table 5.7.1 Incremental MPC Estimates for Combination Cooler Refrigeration Products

Product Class (AV, ft^3)	C-13A	C-3A	C-9
EL 1 (%—Cost)	10% – $2.21	10% – $17.55	10% – $0.00
EL 2 (%—Cost)	19% – $4.61	18% – $19.45	20% – $3.61
EL 3 (%—Cost)	24% – $72.82	21% – $59.16	26% – $45.72
EL 4 – Max Tech (%—Cost)	27% – $127.07	25% – $180.83	31% – $173.81

Although DOE currently has product classes for combination cooler refrigeration products from these three product class families (C-3A, C-3A-BI; C-9, C-9-BI, C-9I, C-9I-BI; C-13A, C13A-BI), DOE could similarly construct representative cost-efficiency curves for any potential combination product class combining a cooler compartment with any of the 42 existing refrigerator, refrigerator-freezer, or freezer product classes using the 2021 RFs Preliminary Analysis. This could allow DOE to consider energy conservation standards for combination cooler refrigeration products not available on the market, but that may become available in the future. DOE welcomes feedback on this approach and on whether energy conservation standards for additional product classes of combination cooler refrigeration products would be appropriate.

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CHAPTER 6. MARKUPS ANALYSIS

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CHAPTER 6. MARKUPS ANALYSIS

6.1 INTRODUCTION

To carry out its analyses, the U.S. Department of Energy (DOE) develops appropriate markups (*e.g.*, manufacturer markups, wholesaler markups, retailer markups) in the distribution chain and sales taxes to convert manufacture production cost (MPC) estimates derived in the engineering analysis to consumer prices, which are then used in the LCC and PBP analysis.

As a first step, DOE converts the MPC to the manufacturer selling price (MSP) by applying a manufacturer markup. The MSP is the price the manufacturer charges its first customer, when selling into the product distribution channels. DOE relied on publicly available financial data to estimate an industry-average manufacturer markup.

DOE further develops markups for each actor in the distribution chain (after the product leaves the manufacturer). At each point in a distribution channel, companies mark up the price of a product to cover their business costs and profit margin. In financial statements, gross margin (“GM”) is the difference between the company revenue and the company cost of goods sold (“CGS”). The GM takes account of the expenses of companies in the distribution channel, including overhead costs (sales, general, and administration); research and development (“R&D”); interest expenses; depreciation; and taxes—and company profits. To cover costs and to contribute positively to company cash flow, the price of products must include a markup. Products command lower or higher markups depending on company expenses associated with the product and the degree of market competition.

DOE estimates a baseline markup and an incremental markup for each market participant besides manufacturers. DOE defines a baseline markup as a multiplier that converts the MSP of equipment with baseline efficiency to the consumer purchase price. An incremental markup is defined as the multiplier to convert the incremental increase in MSP of higher efficiency equipment to the consumer purchase price. Because companies mark up the price at each point in the distribution channel, both overall baseline and incremental markups are dependent on the distribution channel, as described in Section 6.1.1.

6.1.1 Distribution Channels

The appropriate markups for determining consumer product prices depend on the type of distribution channels through which products move from manufacturers to consumers. At each point in the distribution channel, companies mark up the price of the product to cover their business costs and profit margin.

Data from the Association of Home Appliance Manufacturers (AHAM)[1] indicate that an overwhelming majority of residential appliances are sold through retail outlets. According to feedback from manufacturers, most miscellaneous refrigeration products (MREFs) follow a distribution channel in which manufacturers sell the products directly to retailers, who then sell to consumers. Manufacturers also indicated that a small percentage of freestanding MREFs and all built-in MREFs are sold through a separate distribution channel, in which manufacturers sell the products to wholesalers, who in turn sell the products to dealers or retailers then to consumers. These two distribution channels considered in the markup analysis are shown in Figure 6.1.1 below.

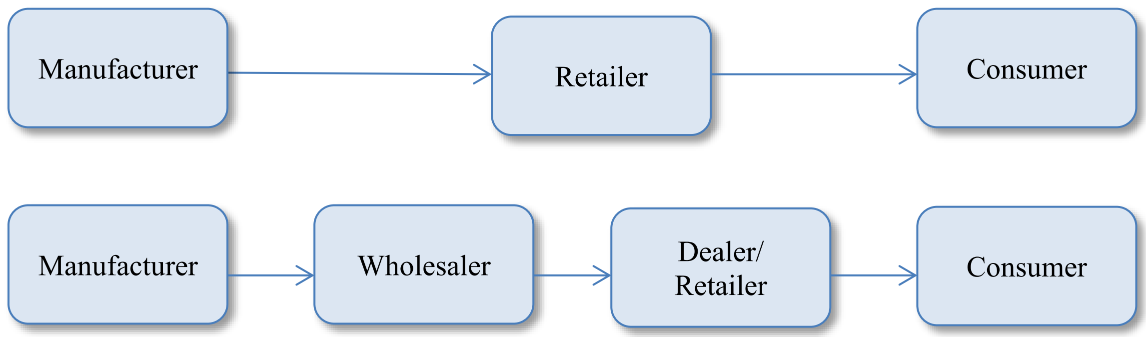

Figure 6.1.1 Distribution Channels for Miscellaneous Refrigeration Products

Based on manufacturer feedback, DOE assumes that 90% of freestanding compact coolers and 75% of freestanding coolers and freestanding combination cooler refrigerator products go through the direct retail channel, and the rest go through the wholesaler-to-retailer channel. For built-in products, all units go through the wholesaler-to-retailer channel.

6.2 MANUFACTURER MARKUP

DOE uses the manufacturer markups to convert manufacturer production costs to manufacturer selling prices. The manufacturer markup covers all manufacturer non-production costs (*e.g.,* SG&A, R&D, and interest) and profit.

DOE considered the average manufacturer markup from the October 2016 MREF Direct Final Rule to be the most robust product-specific data available.[2] DOE estimated the industry average manufacturer markup to be 1.25 for freestanding compact coolers, and 1.41 for the rest of product classes.

6.3 MARKUPS FOR RETAILER AND WHOLESALER

A change in energy efficiency standards usually increases the manufacturer selling price that wholesalers or retailers pay. In the past, DOE used the same markups as for baseline products to estimate the product price of more efficient product. Applying a fixed markup on higher manufacturer selling price would imply an increase in the dollar margin earned by retailers and wholesalers, and an increase in per-unit profit.

Based on microeconomic theory, the degree to which firms can pass along a cost increase depends on the level of market competition, as well as the market structure on both the supply and demand side (e.g., supply and demand elasticity). DOE examined industry data from IBISWorld and the results suggest the industry groups involved in appliance retail and wholesale exhibit a strong degree of competition (see appendix 6A).[a] In addition, consumer demand for household appliances is relatively inelastic (*i.e.,* demand is not expected to decrease substantially with an increase in the price of products). Under relatively competitive markets, it may be tenable for retailers or wholesalers to maintain a fixed markup for a short period of time after an input price increase, but the market competition should eventually force them to readjust their markups to reach a medium-term equilibrium in which per-unit profit is relatively unchanged before and after standards are implemented.

Thus, DOE concluded that applying fixed markups for both baseline products and higher-priced products meeting a standard is not viable in the medium to long term considering the competitive nature of the appliance retail industry. DOE developed the incremental markup approach based on the widely accepted economic view that firms are not able to sustain a persistently higher dollar profit in a competitive market in the medium term. If the price of the product increases under standards, the only way to maintain the same dollar profit as before is for the markup (and percent gross margin) to decline.

To estimate the markup under standards, DOE derived an incremental markup that is applied to the incremental product costs of higher efficiency products. The overall markup on the products meeting standards is an average of the markup on the component of the cost that is equal to the baseline product and the markup on the incremental cost accrued due to standards, weighted by the share of each in the total cost of the standards-compliant product.

DOE's incremental markup approach allows the part of the cost that is thought to be affected by the standard to scale with the change in manufacturer price. The income statements DOE used to develop retailer and wholesaler markups itemize firm costs into a number of expense categories, including direct costs to purchase or install the product, operating labor and occupancy costs, and other operating costs and profit. Although retailers and wholesalers tend to handle multiple commodity lines, DOE contends that these aggregated data provide the most accurate available indication of the cost structure of distribution channel participants.

DOE uses these income statements to divide firm costs between those that are not likely to scale with the manufacturer price of products (labor and occupancy expenses, or "invariant" costs) and those that are (operating expenses and profit, or "variant" costs). For example, when the manufacturer selling price of products increases, only a fraction of a retailer's expenses increase (operating expenses and profit), while the remainder can be expected to stay relatively constant (labor and occupancy expenses). If the unit price of freestanding compact cooler increases by 20 percent under standards, it is unlikely that the cost of secretarial support in an administrative office or office rental expenses will increase proportionally.

See Appendix 6A for further evidence supporting the use of incremental markups in this analysis. The derivation of incremental markups for retailers and wholesalers is described in the following sections.

6.3.1 Approach for Retailer Markups

DOE based the retailer markups for MREFs on financial data for electronics and appliance stores from the 2017 U.S. Census *Annual Retail Trade Survey (ARTS)*[3], which is the

[a] IBISWorld, US Industry Reports (NAICS): www.ibisworld.com (Last accessed March 2021.)

most recent survey available with detailed operating expenses for this particular sector. DOE collected itemized financial data that break down cost components incurred by firms in this sector. DOE assumes that the income statements faithfully represent the various average costs incurred by firms selling home appliances.

The baseline markup relates the manufacturer selling price of baseline products to the retailer sales price. DOE considers baseline models to be products sold under existing market conditions (*i.e.,* without newly amended energy efficiency standards). DOE calculated the baseline markup (MU_{BASE}) for retailers as an average markup using the following equation:

$$MU_{BASE} = \frac{CGS_{RTL} + GM_{RTL}}{CGS_{RTL}}$$

Eq. 6.1

where:

MU_{BASE} = baseline retailer markup,
CGS_{RTL} = retailer's cost of goods sold,
GM_{RTL} = retailer's gross margin,

To estimate incremental retailer markups, DOE divides retailers' operating expenses into two categories: (1) those that do not change when CGS increases due to amended efficiency standards ("fixed"), and (2) those that increase proportionately with CGS ("variable"). DOE defines labor and occupancy expenses as fixed costs, because these costs are not likely to increase as a result of a rise in CGS due to amended efficiency standards. All other expenses, as well as the net profit, are assumed to vary in proportion to CGS. Although it is possible that some of the other expenses may not scale with CGS, DOE is inclined to take a more conservative position and include these as variable costs. (Note: Under DOE's approach, a high fixed cost component yields a low incremental markup.)

DOE calculated the incremental markup (MU_{INCR}) for retailers using the following equation:

$$MU_{INCR} = \frac{CGS_{RTL} + VC_{RTL}}{CGS_{RTL}}$$

Eq. 6.2

where:

MU_{INCR} = incremental retailer markup,
CGS_{RTL} = retailer's cost of goods sold, and
VC_{RTL} = retailer's variable costs.

6.3.2 Derivation of Retailer Markups

The 2017 ARTS data for electronics and appliance stores provide total sales data and detailed operating expenses that are most relevant to MREF retailers. To construct a complete data set for estimating markups, DOE needed to estimate CGS and GM. The most recent 2017 ARTS publishes a separate document containing historical sales and gross margin for household appliance stores. DOE took the GM as a percent of sales reported for 2017 and combined that percent with detailed operating expenses data from 2017 ARTS to construct a complete income statement for electronics and appliance stores to estimate both baseline and incremental markups. Table 6.3.1 shows the calculation of the baseline retailer markup.

Table 6.3.1 Data for Baseline Markup Calculation: Electronics and Appliance Stores

Kind of business item	Amount ($1,000,000)
Sales	99,401
Cost of Goods Sold (CGS)	66,897
Gross Margin (GM)	32,504
Baseline Markup = (CGS+GM)/CGS	**1.49**

Source: U.S. Census, 2017 Annual Retail Trade Survey

Table 6.3.2 shows the breakdown of operating expenses using the 2017 ARTS data. The incremental markup is calculated as 1.24.

Table 6.3.2 Data for Incremental Markup Calculation: Electronics and Appliance Stores

	Amount ($1,000,000)
Sales	99,401
Cost of Goods Sold (CGS)	*66,897*
Gross Margin (GM)	*32,504*
Labor & Occupancy Expenses ("Fixed")	
Annual payroll	10,226
employer costs for fringe benefit	1,574
Contract labor costs including temporary help	157
Purchased utilities, total	459
Purchased Repairs and Maintenance to Buildings, Structures, and Offices	266
Cost of purchased professional and technical services	743
Purchased communication services	290
Lease and Rental Payments for Land, Buildings, Structures, Store Space, and Offices	2,686
Subtotal:	16,401
Other Operating Expenses & Profit ("Variable")	
Expensed equipment	87
Cost of purchased packaging and containers	51
Other materials and supplies not for resale	387
Cost of purchased transportation, shipping and warehousing services	471
Cost of purchased advertising and promotional services	1,392
Cost of purchased software	93
Purchased Repairs and Maintenance to Machinery and Equipment	118
Lease and Rental Payments for Machinery, Equipment, and Other Tangible Items	89
Cost of data processing and other purchased computer services	66
Commission expenses	235
Depreciation and amortization charges	1,019
Taxes and license fees (mostly income taxes)	382
Other operating expenses	2,312
Net profit before tax (Operating profit)	*9,401*
Subtotal:	16,103
Incremental Markup = (CGS+Total Other Operating Expenses and Profit)/CGS	**1.24**

Source: U.S. Census, 2017 Annual Retail Trade Survey

6.3.3 Approach for Wholesaler Markups

DOE developed baseline and incremental wholesaler markups using the firm income statement for household appliances and electrical and electronic goods merchant wholesale sector from the 2017 U.S. Census *Annual Wholesale Trade Report ("AWTR")*.[4] Baseline markups cover all the wholesaler's costs (both fixed and variable). DOE calculated the baseline markup for wholesalers using the following equation.

$$MU_{BASE} = \frac{CGS_{WHOLE} + GM_{WHOLE}}{CGS_{WHOLE}}$$

Eq. 6.3

where:

MU_{BASE} = wholesaler's baseline markup,
CGS_{WHOLE} = wholesaler's cost of goods sold, and
GM_{WHOLE} = wholesaler's gross margin,

DOE used the following equation to calculate the incremental markup (MU_{INCR}) for wholesalers.

$$MU_{INCR} = \frac{CGS_{WHOLE} + +VC_{WHOLE}}{CGS_{WHOLE}}$$

Eq. 6.4

where:

MU_{INCR} = wholesaler's incremental markup,
CGS_{WHOLE} = wholesaler's cost of goods sold, and
VC_{WHOLE} = wholesaler's variable costs.

6.3.4 Derivation of Wholesaler Markups

The 2017 AWTR data for household appliances and electrical and electronic goods merchant wholesalers provide total sales data and detailed operating expenses representing MREF wholesalers, similar to the data used in developing retailers markups. Hence, DOE took the same approach as described in section 6.3.2 to construct a complete data set for that particular sector and estimated their baseline and incremental markups. Table 6.3.3 presents the calculation of the baseline retailer markup.

Table 6.3.3 Data for Baseline Markup Calculation: Household Appliances and Electrical and Electronic Goods Merchant Wholesale

Kind of business item	Amount ($1,000,000)
Sales	583,634
Cost of Goods Sold (CGS)	433,056
Gross Margin (GM)	150,578
Baseline Markup = (CGS+GM)/CGS	**1.35**

Source: U.S. Census, 2017 Annual Wholesale Trade Report

Table 6.3.4 shows the breakdown of operating expenses using the 2017 AWTR data. The incremental markup is calculated as 1.20.

Table 6.3.4 Data for Incremental Markup Calculation: Household Appliances and Electrical and Electronic Goods Merchant Wholesale

	Amount ($1,000,000)
Sales	583,634
Cost of Goods Sold (CGS)	*433,056*
Gross Margin (GM)	*150,578*
Labor & Occupancy Expenses ("Fixed")	
Total payroll, other employee wages	44,715
Total fringe benefits	10,082
Temporary staff and leased employee expenses	1,797
Rental costs of machinery and equipment	-
Rental costs of buildings	3,440
Cost of repair to building	566
Cost of repair to machinery and equipment	592
Purchased communication services	973
Purchased utilities, total	522
Subtotal:	62,687
Other Operating Expenses & Profit ("Variable")	
Purchased professional and technical services	5,087
Data processing and other purchased computer services	649
Expensed computer hardware and other equipment	1,147
Expensed purchases of software	889
Advertising and promotion services	5,627
All other expenses	-
Purchased transportation, shipping and warehousing services	-
Taxes and license fees	843
Total depreciation	4,956
Commission expenses	3,074
Purchases of packaging material and containers	-
Purchases of other materials, parts, and supplies (not for resale)	943
Net profit before tax (Operating profit)	*51,636*
Subtotal:	87,891
Incremental Markup = (CGS+Total Other Operating Expenses and Profit)/CGS	**1.20**

Source: U.S. Census, 2017 Annual Wholesale Trade Report

6.4 SALES TAXES

The sales tax represents state and local sales taxes that are applied to the consumer product price. The sales tax is a multiplicative factor that increases the consumer product price. DOE used state and local tax data provided by the Sales Tax Clearinghouse.[5] DOE assigned state-level average tax values for each household used in the life-cycle cost analysis, as shown in Table 6.4.1.

Table 6.4.1 Average Sales Tax Rates by State

State	Average State and Local Tax Rate %	State	Average State and Local Tax Rate %	State	Average State and Local Tax Rate %
Alabama	8.65	Kentucky	6.00	North Dakota	6.25
Alaska	1.30	Louisiana	9.40	Ohio	7.20
Arizona	7.30	Maine	5.50	Oklahoma	8.55
Arkansas	9.15	Maryland	6.00	Oregon	--
California	8.65	Massachusetts	6.25	Pennsylvania	6.35
Colorado	6.35	Michigan	6.00	Rhode Island	7.00
Connecticut	6.35	Minnesota	7.45	South Carolina	7.45
Delaware	--	Mississippi	7.05	South Dakota	6.00
Dist. of Columbia	6.00	Missouri	7.00	Tennessee	9.50
Florida	7.10	Montana	--	Texas	7.95
Georgia	7.35	Nebraska	6.10	Utah	7.15
Hawaii	4.00	Nevada	8.25	Vermont	6.10
Idaho	6.00	New Hampshire	--	Virginia	5.75
Illinois	8.60	New Jersey	6.60	Washington	9.25
Indiana	7.00	New Mexico	7.05	West Virginia	6.15
Iowa	6.95	New York	8.45	Wisconsin	5.45
Kansas	8.40	North Carolina	7.00	Wyoming	5.35

6.5 SUMMARY OF MARKUPS

Table 6.5.1 summarizes the national average markups at each stage in the distribution channel and the average sales tax.

Table 6.5.1 Summary of Markups for Miscellaneous Refrigeration Products

Markup	Manufacturer → Retailer → Consumer		Manufacturer → Wholesaler → Retailer → Consumer	
	Baseline Markup	**Incremental Markup**	**Baseline Markup**	**Incremental Markup**
Manufacturer	1.25/1.41		1.25/1.41	
Wholesaler	-	-	1.35	1.20
Retailer	1.49	1.24	1.49	1.24
Sales Tax	1.073		1.073	
Overall	2.00/2.25	1.66/1.88	2.70/3.04	2.00/2.25

REFERENCES

1. Association of Home Appliance Manufacturers. *Fact Book 2009*. 2009. AHAM: Washington, D.C.

2. U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy. Energy Conservation Program: Energy Conservation Standards for Consumer Products and Commercial and Industrial Equipment: Miscellaneous Refrigeration Products; Direct Final Rule Technical Support Document; EERE-2011-BT-STD-0043-0118. September 9, 2016. (Last accessed February 23, 2021.) https://www.regulations.gov/document/EERE-2011-BT-STD-0043-0118.

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5. Sales Tax Clearinghouse Inc. *State Sales Tax Rates Along with Combined Average City and County Rates*. July 2021. (Last accessed July 1, 2021.) http://thestc.com/STrates.stm.

CHAPTER 7. ENERGY USE ANALYSIS

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7.1 INTRODUCTION

To perform the life-cycle cost (LCC) and payback period (PBP) calculations described in chapter 8, the U.S. Department of Energy (DOE) determines the savings in operating cost that consumers would reap from more-efficient products. DOE used data on annual energy consumption, along with energy prices, to develop the consumer operating cost. This chapter describes how DOE determined the annual energy consumption of miscellaneous refrigeration products (MREFs) for the LCC and PBP analysis.

The goal of the energy use analysis is to generate a range of energy use values that reflects actual product use in U.S. homes by new products at various efficiency levels. The engineering analysis described in chapter 5 reports energy use derived from the DOE test procedure. This test procedure produces standardized results that can be used to assess or compare the performance of products operating under specified conditions. For each volume and considered efficiency level, DOE derived the energy consumption as measured by the DOE test procedure for MREFs.

7.2 ENERGY USE DATA

7.2.1 Overall approach

DOE determined a range of annual energy use of MREFs as a function of the unit's volume. DOE developed distributions of adjusted volume for product classes with more than one representative unit (the freestanding compact class and the corresponding built-in product class) based on the capacity distributions reported in the TraQline® wine chiller data spanning from Q1 2019 to Q2 2021. TraQline is a market research company that specializes in tracking consumer purchasing behavior (150,000+ consumers) across a wide range of products using quarterly online surveys.[a] DOE also developed a sample of households that use MREFs based on the TraQline wine chiller data. For each sampled household, DOE randomly assigned a product volume from the volumes analyzed in the engineering analysis. For each volume and considered efficiency level, DOE derived the energy consumption as measured by the DOE test procedure at 10 CFR part 430, subpart B, appendix A.

For this preliminary analysis, DOE analyzed the energy use for the product classes that were directly analyzed in the engineering analysis (see chapter 5 of this TSD), which represent the majority of the industry shipments for MREFs. These product classes include the freestanding cooler (Cooler-F) and freestanding compact cooler (Cooler-FC) product classes as well as the C-13A compact cooler-all-refrigerator product class. These three product classes represent the majority of models in DOE's compliance certification management system (CCMS) database.[1] In addition, DOE evaluated the energy use for two not-directly analyzed product classes presented in the engineering analysis: The combination cooler C-3A and C-9

[a] www.traqline.com

product classes. Finally, DOE notes that the energy use of each product class is considered to be representative of its corresponding built-in product class.

7.2.2 MREF Product Volumes

As discussed in chapter 5 of this TSD, for this preliminary analysis, DOE evaluated MREF units representing the most common adjusted volumes within a product class or adjusted volumes representative of the overall range available, based on models listed in DOE's CCMS database.[1] For the freestanding compact product class, DOE analyzed two representative units with two different product adjusted volumes (3.1 and 5.1 ft^3). To determine the market distribution of product adjusted volumes for this product class, DOE used data from the TraQline® wine chiller survey. The survey asked MREF owners about the bottle capacity of their wine chillers, and DOE converted the number of bottles to interior volume in cubic feet using the model information reported in DOE's CCMS database. For all other evaluated product classes, DOE assumed that the adjusted volume of the representative unit was also representative of the market. Table 7.2.1 shows the volume distribution used for the evaluated MREF product classes.

Table 7.2.1 Distribution of Adjusted Interior volumes by Product Class

Adjusted Volume (ft^3)	Percentage
Cooler-FC	
3.1	82.1
5.1	17.9
Cooler-F	
15.3	100.0
C-3A	
21	**100.0**
C-9	
29.3	**100.0**
C-13A	
5.1	100.0

7.3 ANNUAL ENERGY CONSUMPTION BY EFFICIENCY LEVEL

This section reports the annual energy consumption calculated for MREFs at the efficiency levels described in chapter 5. Table 7.3.1 through Table 7.3.5 show the considered efficiency levels and corresponding average annual energy consumption for each of the MREF product classes and volumes analyzed.

Table 7.3.1 Freestanding Compact Coolers: Average Annual Energy Use by EL

Efficiency level	Cooler-FC (3.1 cu. ft.)		Cooler-FC (5.1 cu. ft.)	
	% Better than the Baseline	kWh	% Better than the Baseline	kWh
0	0%	180.23	0%	195.99
1	20%	144.18	20%	156.79
2	30%	126.16	30%	137.19
3	45%	99.13	49%	99.95
4	50%	90.11	50%	97.99
5	51%	88.31	52%	94.07

Table 7.3.2 Freestanding Cooler: Average Annual Energy Use by EL

Efficiency level	% Better than the Baseline	kWh
0	0%	276.36
1	10%	248.73
2	20%	221.09
3	30%	193.45
4	35%	179.64
5	39%	168.58

Table 7.3.3 C-3A: Average Annual Energy Use by EL

Efficiency level	% Better than the Baseline	kWh
0	0%	226.37
1	10%	203.73
2	18%	185.62
3	21%	178.83
4	25%	169.78

Table 7.3.4 C-9: Average Annual Energy Use by EL

Efficiency level	% Better than the Baseline	kWh
0	0%	311.19
1	10%	280.07
2	20%	248.96
3	26%	230.28
4	31%	214.72

Table 7.3.5 C-13A: Average Annual Energy Use by EL

Efficiency level	% Better than the Baseline	kWh
0	0%	223.94
1	10%	201.55
2	19%	181.39
3	24%	170.20
4	27%	163.48

REFERENCES

1. U.S. Department of Energy. *Compliance Certification Management System*. February 9, 2021. (Last accessed July 1, 2021.) https://www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A*.

CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

This chapter describes the U.S. Department of Energy's (DOE's) method for analyzing the economic impacts on individual consumers from potential energy efficiency standards for miscellaneous refrigeration products (MREFs). The effects of standards on individual consumers include a change in purchase price (usually an increase) and a change in operating costs (usually a decrease). This chapter describes three metrics DOE used to determine the impact of standards on individual consumers:

- **Life-cycle cost** (LCC) is the total consumer expense during the lifetime of an appliance (or other equipment), including purchase expense and operating costs (including energy expenditures). DOE discounts future operating costs to the year of purchase and sums them over the lifetime of the product.

- **Payback period** (PBP) measures the amount of time it takes a consumer to recover the higher purchase price of a more energy efficient product through lower operating costs. DOE calculates a simple payback period which does not discount operating costs.

- **Rebuttable payback period** is a special case of the PBP. Whereas LCC is estimated for a range of inputs that reflect real-world conditions, rebuttable payback period is based on laboratory conditions as specified in the DOE test procedure.

Inputs to the LCC and PBP calculations are described in sections 8.2, 8.3 and 8.4. Results of the LCC and PBP analysis are presented in section 8.5.

DOE performed the calculations discussed herein using a program written in Python. However, the calculations are illustrated with a Microsoft Excel® spreadsheet that is accessible at https://www.regulations.gov/docket/EERE-2011-BT-STD-0043. Details and instructions for using the spreadsheet are provided in appendix 8A of this TSD.

8.1.1 General Analysis Approach

Life-cycle cost is calculated using the following equation:

$$LCC = TIC + \sum_{t=0}^{N-1} \frac{OC_t}{(1+r)^t}$$

Eq. 8.1

Where:

LCC =	life-cycle cost (in dollars),
TIC =	total installed cost in dollars,
$\sum$ =	sum over the appliance lifetime, from year 1 to year N,
N =	lifetime of the appliance in years,
OC =	operating cost in dollars,
r =	discount rate, and
t =	year to which operating cost is discounted.

The payback period is the ratio of the increase in total installed cost (i.e., from a less energy efficient design to a more efficient design) to the decrease in annual operating expenditures. This type of calculation results in what is termed a simple payback period, because it does not take into account changes in energy expenses over time or the time value of money. That is, the calculation is done at an effective discount rate of zero percent. The equation for PBP is:

$$PBP = \frac{\Delta TIC}{\Delta OC}$$

Eq. 8.2

Where:

ΔTIC =	difference in total installed cost between a more energy efficient design and the baseline design, and
ΔOC =	difference in annual operating expenses.

Payback periods are expressed in years. Payback periods greater than the life of the product indicate that the increased total installed cost is not recovered through reduced operating expenses.

The data inputs to PBP are the average total installed cost of the product to the consumer for each EL and the average annual (first year) operating costs for each efficiency level. The inputs to the total installed cost are the product price and the installation cost. The inputs to the operating costs are the annual energy cost and the annual maintenance cost. The PBP uses the same inputs as the LCC analysis, except that electricity price trends are not required. Since the PBP is a "simple" payback, the required electricity cost is only for the year in which a new efficiency standard is to take effect—in this case, 2029.

DOE also calculates a rebuttable PBP, which is the time it takes the consumer to recover the assumed higher purchase cost of more energy-efficient product as a result of lower energy costs. Numerically, the rebuttable PBP is the ratio of the increase in purchase cost (i.e., from a less efficient design to a more efficient design) to the decrease in annual energy expenditures, which is the decrease in first year annual energy cost as calculated from the DOE test procedure. The calculation excludes repair costs and maintenance costs. DOE does not have a separate section on rebuttable PBP in this chapter, because the PBP that DOE calculated as part of its regular analysis is identical to the rebuttable PBP for MREFs. This is because DOE used the annual energy use measured by the DOE test procedure and did not include any repair and maintenance costs in its regular PBP calculation.

Recognizing that inputs to the determination of consumer LCC and PBP may be either variable or uncertain, DOE conducts the LCC and PBP analysis by modeling both the uncertainty and variability of the inputs using Monte Carlo simulation and probability distributions for inputs. Appendix 8B provides a detailed explanation of Monte Carlo simulation and the use of probability distributions and discusses the tool used to incorporate these methods.

DOE calculates impacts relative to a case without amended or new energy conservation standards (referred to as the "no-new-standards case"). In the no-new-standards case, some consumers may purchase products with energy efficiency higher than a baseline model. For any given standard level under consideration, consumers expected to purchase a product with efficiency equal to or greater than the considered level in the no-new-standards case would be unaffected by that standard.

DOE calculates the LCC and PBP as if all consumers purchase the product in the expected initial year of compliance with a new or amended standard. At this time, the expected compliance date of potential energy conservation standards for MREFs manufactured in, or imported into, the United States is in 2029. Therefore, DOE conducted the LCC and PBP analysis assuming purchases take place in 2029.

8.1.2 Overview of Analysis Inputs

The LCC analysis uses inputs for establishing (1) the purchase expense, otherwise known as the total installed cost, and (2) the operating costs over the product lifetime.

The primary inputs for establishing the total installed cost are:

- *Baseline manufacturer cost*: The costs incurred by the manufacturer to produce products that meet current minimum efficiency standards, or another efficiency level designated as the baseline for analysis.

- *Standard-level manufacturer cost*: The manufacturer cost (or cost increase) associated with producing products that meet particular efficiency levels above the baseline.

- *Markups and sales tax*: The markups and sales tax associated with converting the manufacturer cost to a consumer product cost.

- *Installation cost*: All costs required to install the product, including labor, overhead, and any miscellaneous materials and parts.

The primary inputs for calculating the operating cost are:

- *Product energy consumption*: The product energy consumption is the site energy use associated with operating the product.

- *Energy prices*: The prices consumers pay for energy (*e.g.*, electricity or natural gas).

- *Energy price trends*: The annual rates of change projected for energy prices during the study period.

- *Repair costs and maintenance costs*: Repair costs are associated with repairing or replacing components that fail. Maintenance costs are associated with maintaining the operation of the product.

- *Lifetime*: The age at which the product is retired from service.

- *Discount rates*: The rates at which DOE discounts future expenditures to establish their present value.

The inputs for calculating the PBP are the total installed cost and the first-year operating costs. The inputs to operating costs are the first-year energy cost and the annualized repair cost and the annualized maintenance cost, where applicable. The PBP uses the same inputs as the LCC analysis, except the PBP does not require energy price trends or discount rates.

Figure 8.1.1 depicts the relationships among the inputs to installed cost and operating cost for calculating a product's LCC and PBP. In the figure, the tan boxes indicate inputs, the green boxes indicate intermediate outputs, and the blue boxes indicate final outputs.

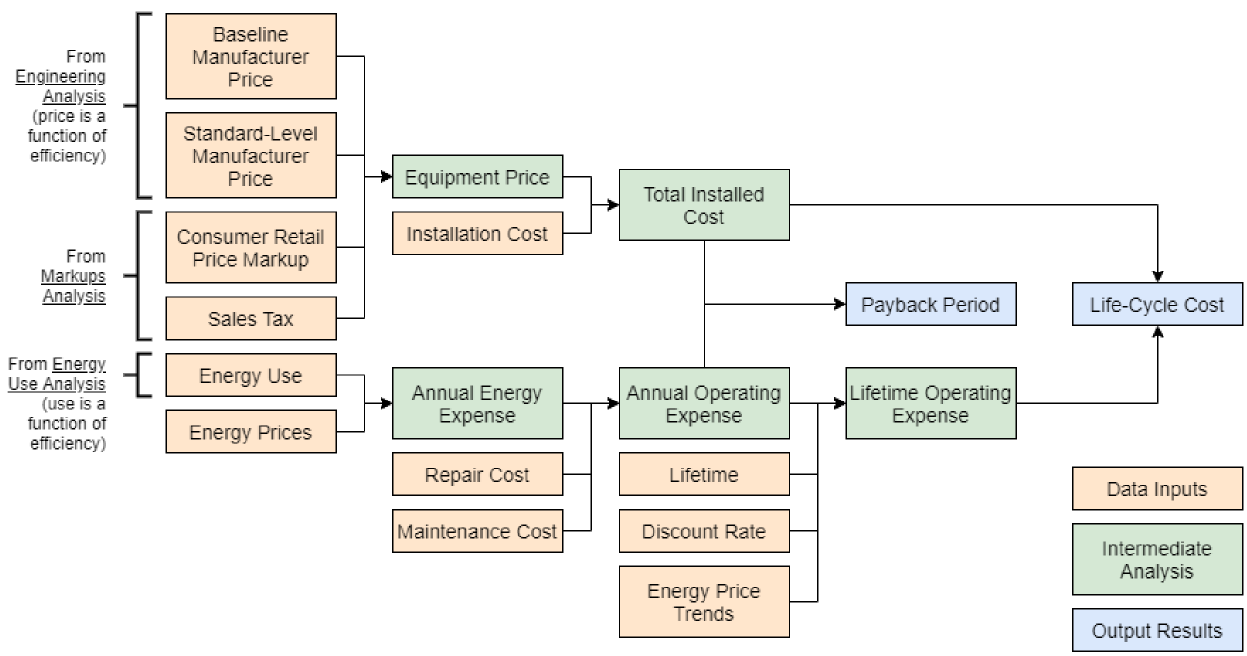

Figure 8.1.1 Flow Diagram of Inputs for the Determination of LCC and PBP

Table 8.1.1 provides a summary of inputs, with a greater degree of detail, used in the analysis.

Table 8.1.1 Summary of Inputs to Life-Cycle Cost and Payback Period

Inputs	**Average or Typical Value**	**Characterization**
Total Installed Cost Inputs		
Product Price	Varies by distribution channel, efficiency level, and product class	Single-point value
Sales Tax	5.6% - 8.2%	Varies by region
Operating Cost Inputs		
Power Rating	Varies by efficiency level and product class	Single-point value
Electricity Prices	Average ($2020): 0.10 – 0.23 $/kWh Marginal ($2020): 0.09 – 0.27 $/kWh	Vary by region
Electricity Price Trends	*AEO 2021* reference case	Vary by census division
Product Lifetime	Compact coolers: 10.3 years Full-size coolers: 17.3 years	Weibull distribution
Discount Rates	Average: 4.25%	Vary by consumer income
Assumed Date Standards Become Effective	2029	Single-point value

8.1.3 Sample of MREF Users

The LCC and PBP calculations detailed here are for a representative sample of individual MREF users. By developing consumer samples, DOE accounts for the variability in energy consumption and energy price associated with a range of consumers.

DOE acquired ten-years of historical data from TraQline's wine chiller survey in order to develop a sample of MREF consumers for the LCC and PBP analysis. TraQline is a market research company that specializes in tracking consumer purchasing behavior across a wide range of products using quarterly online surveys.[a] The survey panel is weighted against the U.S. Census based on their demographic characteristic to make the sample representative of the U.S. population. The wine chiller survey asked respondents about the product features of the wine chillers they recently purchased, as well as the purchasing channel of the products. To account for the more recent MREF consumers, DOE used the last two and half years of survey data (2019 Q1 to 2021 Q2) to construct the household sample used in this preliminary analysis.

Recognizing that several inputs to the determination of consumer LCC and PBP are either variable or uncertain, DOE conducted the LCC and PBP analyses by modeling the variability in the inputs using Monte Carlo simulation and probability distributions. Each Monte

[a] For more information see www.traqline.com.

Carlo simulation consists of 10,000 LCC and PBP calculations. The model performs each calculation using input values that are either sampled from probability distributions and household samples or characterized with single point values.

8.2 TOTAL INSTALLED COST INPUTS

DOE uses the following equation to define the total installed cost.

$$TIC = CPC + IC$$

Eq. 8.3

Where:

TIC = total installed cost,
CPC = consumer purchase cost, and
IC = installation cost.

The consumer purchase cost is equal to the manufacturer cost multiplied by markups, and where applicable, sales tax. The cost varies based on the distribution channel through which the consumer purchases the product. The installation cost represents all costs to the consumer for installing the product, including labor, overhead, and any miscellaneous materials and parts. The installation cost may vary by efficiency level.

The rest of this section provides information about each of the inputs that DOE used to calculate the total installed cost of MREFs.

8.2.1 Manufacturer Costs

DOE developed manufacturer costs at each efficiency level for all the product classes for MREFs as described in chapter 5 of this TSD.

8.2.2 Overall Markup

For a given distribution channel, the overall markup is the value determined by multiplying all the associated markups and the applicable sales tax together to arrive at a single overall distribution chain markup value. Because there are baseline and incremental markups associated with the various market participants, the overall markup is also divided into a baseline markup (*i.e.*, a markup used to convert the baseline manufacturer price into a consumer price) and an incremental markup (*i.e.*, a markup used to convert a standard-compliant manufacturer cost increase due to an efficiency increase into an incremental consumer price). Refer to chapter 6 of this TSD for details.

8.2.3 Application of Learning Rate for Product Prices

Examination of historical price data for certain appliances and equipment that have been subject to energy conservation standards indicates that an assumption of constant real prices may, in many cases, overestimate long-term trends in appliance and equipment prices. Economic literature and historical data suggest that the real costs of these products may, in fact, trend downward over time according to "learning" or "experience" curves. Desroches *et al*. (2013) summarizes the data and literature that is relevant to price projections for selected appliances and equipment.[1] The extensive literature on the "learning" or "experience" curve phenomenon is typically based on observations in the manufacturing sector.[b] However, due to the lack of historical price data specific to MREFs, DOE used a constant price assumption to project prices of baseline products and more efficient products to the assumed compliance date of the standard. Thus, projected prices for the LCC and PBP analysis are equal to the 2020 values for each efficiency level in each product class.

8.2.4 Installation Cost

DOE is not aware of any data that suggest the cost of installation changes as a function of efficiency for MREFs. DOE therefore assumed that installation costs are the same regardless of EL and do not impact the LCC or PBP. As a result, DOE did not include installation costs in the LCC and PBP analysis.

8.3 OPERATING COST INPUTS

DOE defines operating cost (OC) using the following equation:

$$OC = EC + RC + MC$$

Eq. 8.4

Where:

EC = energy cost associated with operating the product,
RC = repair cost associated with component failure, and
MC = maintenance cost.

DOE defines the energy cost using the following equation:

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[b] In addition to Desroches (2013), see Weiss, M., Junginger, H.M., Patel, M.K., Blok, K., (2010a). A Review of Experience Curve Analyses for Energy Demand Technologies. Technological Forecasting & Social Change. 77:411-428.

$$EC(t) = AEC(t) \times E_{price}(t)$$

Eq. 8.5

Where:

$AEC(t)$ = annual energy consumption at the site in year t, and
$E_{price}(t)$ = energy price in year t.

The annual energy costs of the equipment are computed from energy consumption per unit for the baseline and the considered efficiency levels, combined with the energy prices. Product lifetime, discount rate, and compliance date of the standard are required for determining the operating cost and for establishing the present value of the operating cost. The remainder of this section provides information about the variables that DOE used to calculate the operating cost for MREFs.

8.3.1 Annual Energy Consumption

For each product class, DOE calculated the annual energy use for each sample product user at each efficiency level, as described in chapter 7 of this TSD. Tables in chapter 7 provide the average annual energy consumption by efficiency level for MREFs.

8.3.2 Energy Prices

8.3.2.1 Recent Energy Prices

DOE derived annual electricity prices in 2020 for each census division using data from EEI Typical Bills and Average Rates reports.[2,3] For the residential sector, the EEI reports provide the total bill assuming household consumption levels of 500, 750 and 1,000 kWh for the billing period for most of the major investor-owned utilities (IOUs) in the country.

Because marginal electricity price more accurately captures the incremental savings associated with a change in energy use from higher efficiency, it provides a better representation of incremental change in consumer costs than average electricity prices. Therefore, DOE applied average electricity prices for the energy use of the product purchased in the no-new-standards case, and marginal electricity prices for the incremental change in energy use associated with the other efficiency levels considered. DOE used the EEI data to define a marginal price as the ratio of the change in the bill to the change in energy consumption.

DOE calculated weighted-average values for average and marginal electricity prices in the residential sector. As the EEI data are published separately for summer and winter, DOE calculated seasonal prices for each division. Each EEI utility in a region was assigned a weight based on the number of consumers it serves. DOE adjusted these regional weighted-average prices to account for systematic differences between IOUs and publicly-owned utilities (POUs), as the latter are not included in the EEI data set.

Table 8.3.1 shows the average and marginal prices for each geographic area for the residential sector. DOE assigned seasonal average and marginal electricity prices for an average summer or winter month to each purchaser in the LCC sample based on its location.

Table 8.3.1 Residential Electricity Prices in 2020

	Geographic Area	Average (2020$/kWh)	Marginal (2020$/kWh)
1	New England Census Division	$0.229	$0.215
2	Middle Atlantic Census Division	$0.178	$0.162
3	East North Central Census Division	$0.138	$0.127
4	West North Central Census Division	$0.126	$0.109
5	South Atlantic Census Division	$0.117	$0.103
6	East South Central Census Division	$0.124	$0.100
7	West South Central Census Division	$0.103	$0.088
8	Mountain North	$0.119	$0.117
9	Mountain South	$0.119	$0.117
10	Pacific Census Division	$0.227	$0.270

8.3.2.2 Future Energy Price Trends

To estimate electricity prices in future years, DOE multiplied the 2020 electricity prices by the forecast of annual average price changes for each of the nine census divisions from EIA's Reference case in the *Annual Energy Outlook 2021* (*AEO 2021)*.[4] The Reference case is a business-as-usual estimate, given known market, demographic, and technological trends. For each consumer sampled, DOE applied the projection for the census division in which the consumer was located. Figure 8.3.1 shows the projected national electricity price trends for the residential sector as a fraction of the 2020 electricity price.

To estimate the trends after 2050, DOE followed past guidelines provided to the Federal Energy Management Program (FEMP) by EIA and used the average rate of change during 2035–2050 to project the electricity price for years after 2050.[c]

[c] The previous FEMP guidance was to use the average rate of change during 2025-2040 (the furthest year *AEO 2013-2016* provided in their price trend projections) to project electricity prices for years after 2040. Because *AEO 2019* provides projections to 2050, DOE used a similar methodology to the original FEMP guidance by applying the average rate of change for the last 15 years of projected values (2035–2050) to project the electricity price for years after 2050.

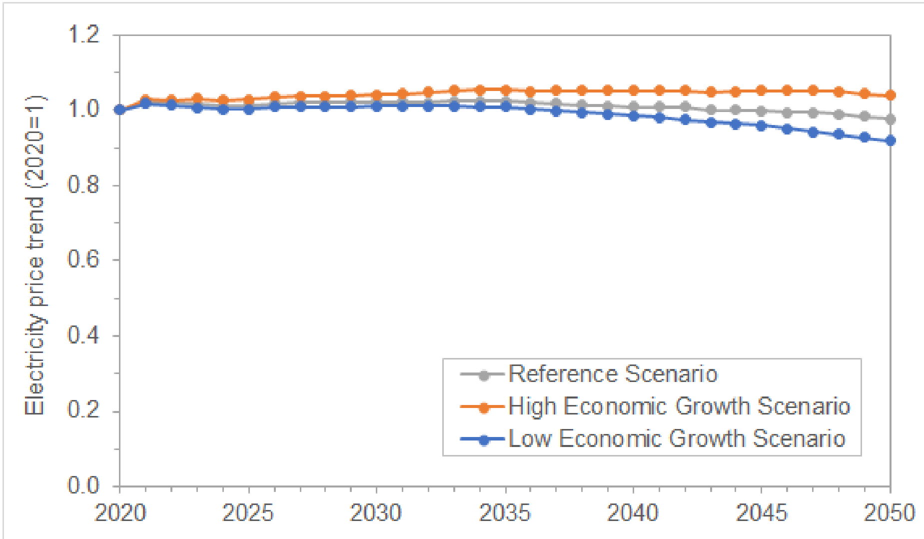

Figure 8.3.1 National Electricity Price Trends Based on *AEO 2021* Reference Case

8.3.3 Repair Costs and Maintenance Costs

The repair cost is the cost to repair the product when a component fails. The maintenance cost is the cost of regular product maintenance. DOE is not aware of any data that suggest the cost of repair or maintenance for MREFs changes as a function of efficiency. DOE therefore assumed that these costs are the same regardless of EL and do not impact the LCC or PBP. As a result, DOE did not include maintenance and repair costs in the LCC and PBP analysis.

8.3.4 Product Lifetime

The product lifetime is the age at which a product is retired from service. Because product lifetime varies, DOE uses a lifetime distribution to characterize the probability a product will be retired from service at a given age.

The short history of MREFs as a regulated product limits the availability of data for the modeling and analysis of product lifetimes. For this preliminary analysis, DOE followed the same approach as the October 2016 Direct Final Rule, which assumed that MREFs operate using the same refrigeration technology as covered refrigerators and refrigerator-freezers.

DOE assumed that the probability function for the annual survival of MREFs would take the form of a Weibull distribution. A Weibull distribution is a probability distribution commonly used to measure failure rates.[d] Its form is similar to an exponential distribution, which models a fixed failure rate, except that a Weibull distribution allows for a failure rate that changes over time in a specific fashion. The cumulative Weibull distribution takes the form:

[d] For reference on the Weibull distribution, see sections 1.3.6.6.8 and 8.4.1.3 of the *NIST/SEMATECH e-Handbook of Statistical Methods*. www.itl.nist.gov/div898/handbook/.

$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}}, for\ x > \theta, \text{ and}$$

$$P(x) = 1 \text{ for } x \leq \theta$$

Eq. 8.6

Where:

P(x) =	probability that the appliance is still in use at age *x*,
x =	age of appliance in years,
θ =	delay parameter, which allows for a delay before any failures occur,
α =	scale parameter, which would be the decay length in an exponential distribution, and
β =	shape parameter, which determines the way in which the failure rate changes through time.

When β = 1, the failure rate is constant over time, giving the distribution the form of a cumulative exponential distribution. In the case of appliances, β commonly is greater than 1, reflecting an increasing failure rate as appliances age. Based on the October 2016 Direct Final Rule, DOE estimated a delay parameter of $\theta = 1$ year for compact coolers and a delay parameter of $\theta = 5$ years for full-size coolers. DOE assumed a maximum lifetime of 40 years for all product classes and an average lifetime of 10.3 years for compact coolers and 17.3 years for full-size coolers. DOE then solved for the scale and shape parameters. Table 8.3.2 shows the Weibull lifetime parameters for MREFs.

Table 8.3.2 Lifetime Parameters for MREFs

Product Class	**Weibull parameters**				
	Alpha (scale)	**Beta (shape)**	**Delay**	**Maximum**	**Average *years***
Compact coolers; C-13A; and C-13A-BI	10.50	1.99	1	40	10.3
Coolers, C-3A; C-3A-BI; C-9, and C-9-BI	13.91	1.68	5	40	17.3

8.3.5 Discount Rates

The discount rate is the rate at which future energy cost savings and operations and maintenance expenditures are discounted to establish their present value. DOE estimated discount rates for residential consumers. DOE calculated discount rates as the weighted average real interest rate across consumer debt and equity holdings.

8.3.5.1 Discount Rates for Residential Applications

The consumer discount rate is the rate at which future operating costs of residential products are discounted to establish their present value in the LCC analysis. The discount rate value is applied in the LCC to future year energy costs and non-energy operations and maintenance costs in order to calculate the estimated net life-cycle cost of products of various efficiency levels and the life-cycle cost savings of higher-efficiency models as compared to the baseline for a representative sample of consumers.

DOE calculates the consumer discount rate using publicly available data (the Federal Reserve Board's *Survey of Consumer Finance*s (SCF)) to estimate a consumer's required rate of return or opportunity cost of funds related to appliances.[5] In the economics literature, opportunity cost reflects potential foregone benefit resulting from choosing one option over another. Opportunity cost of capital refers to the rate of return that one could earn by investing in an alternate project with similar risk; similarly, opportunity cost may be defined as the cost associated with opportunities that are foregone when resources are not put to their highest-value use.[6]

DOE's method views the purchase of a higher efficiency appliance as an investment that yields a stream of energy cost savings. The stream of savings is discounted at a rate reflecting (1) the rates of return associated with other investments available to the consumer, and (2) the observed costs of credit options available to the consumer to reflect the value of avoided debt. DOE notes that the LCC does not analyze the appliance purchase decision, so the implicit discount rate is not relevant in this model. The LCC estimates net present value over the lifetime of the product, so the appropriate discount rate will reflect the general opportunity cost of household funds, taking this time scale into account.

Given the long time horizon modeled in the LCC, the application of a marginal interest rate associated with an initial source of funds is inaccurate. Regardless of the method of purchase, consumers are expected to continue to rebalance their debt and asset holdings over the LCC analysis period, based on the restrictions consumers face in their debt payment requirements and the relative size of the interest rates available on debts and assets. DOE estimates the aggregate impact of this rebalancing using the historical distribution of debts and assets. The discount rate is the rate at which future savings and expenditures are discounted to establish their present value.

DOE estimates separate discount rate distributions for six income groups, divided based on income percentile as reported in the SCF. These income groups are listed in Table 8.3.3. This disaggregation reflects the fact that low and high income consumers tend to have substantially different shares of debt and asset types, as well as facing different rates on debts and assets. Summaries of shares and rates presented in this chapter are averages across the entire population.

Table 8.3.3 Definitions of Income Groups

Income Group	Percentile of Income
1	1st to 20th
2	21st to 40th
3	41st to 60th
4	61st to 80th
5	81st to 90th
6	91th to 99th

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016, and 2019.

8.3.5.2 Shares of Debt and Asset Classes

DOE's approach involved identifying all household debt or equity classes in order to approximate a consumer's opportunity cost of funds over the product's lifetime. This approach assumes that in the long term, consumers are likely to draw from or add to their collection of debt and asset holdings approximately in proportion to their current holdings when future expenditures are required or future savings accumulate. DOE now includes several previously excluded debt types (*i.e.*, vehicle and education loans, mortgages, all forms of home equity loan) in order to better account for all of the options available to consumers.

The average share of total debt plus equity and the associated rate of each asset and debt type are used to calculate a weighted average discount rate for each SCF household (0). The household-level discount rates are then aggregated to form discount rate distributions for each of the six income groups.[e]

DOE estimated the average percentage shares of the various types of debt and equity using data from the SCF for 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016, and 2019.[f] DOE derived the household-weighted mean percentages of each source of across the twenty-one years covered by the eight survey versions. DOE posits that these long-term averages are most appropriate to use in its analysis.

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[e] Note that previously DOE performed aggregation of asset and debt types over households by summing the dollar value across all households and then calculating shares. Weighting by dollar value gave disproportionate influence to the asset and debt shares and rates of higher income consumers. DOE has shifted to a household-level weighting to more accurately reflect the average consumer in each income group.

[f] Note that two older versions of the SCF are also available (1989 and 1992); these surveys are not used in this analysis because they do not provide all of the necessary types of data (*e.g.*, credit card interest rates, etc.). DOE feels that the time span covered by the eight surveys included is sufficiently representative of recent debt and equity shares and interest rates.

Table 8.3.4 Average Shares of Household Debt and Asset Types by Income Group (%)

Type of Debt or Equity	Income Group						
	1	**2**	**3**	**4**	**5**	**6**	**All**
Debt:							
Mortgage	14.3	22.2	33.1	43.3	47.5	37.0	31.0
Home equity loan	1.5	1.8	2.4	3.5	4.6	7.7	3.1
Credit card	15.8	12.2	9.4	6.1	4.0	1.9	9.3
Other installment loan	31.9	28.0	23.9	16.9	11.5	5.9	21.9
Other line of credit	1.4	1.8	1.5	2.0	2.5	2.3	1.8
Other residential loan	0.7	0.4	0.5	0.4	0.3	0.2	0.5
Equity:							
Savings account	19.1	15.0	11.6	9.0	8.2	7.5	12.5
Money market account	3.5	4.3	3.8	3.6	4.4	6.7	4.1
Certificate of deposit	6.0	6.4	4.6	3.8	3.1	3.3	4.8
Savings bond	1.5	1.6	1.4	1.6	1.4	1.2	1.5
State & Local bonds	0.0	0.1	0.2	0.2	0.4	1.3	0.3
Corporate bonds	0.1	0.1	0.1	0.2	0.1	0.4	0.1
Stocks	2.3	3.2	3.8	4.8	6.0	12.2	4.6
Mutual funds	1.8	3.0	3.7	4.8	6.1	12.5	4.5
Total	**100.0**	100.0	100.0	100.0	100.0	100.0	100.0

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016, and 2019.

8.3.5.3 Rates for Types of Debt

DOE estimated interest rates associated with each type of debt. The source for interest rates for mortgages, loans, credit cards, and lines of credit was the SCF for 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016, and 2019, which associates an interest rate with each type of debt for each household in the survey.

DOE adjusted the nominal rates to real rates for each type of debt by using the annual inflation rate for each year (using the Fisher formula).[g] In calculating effective interest rates for home equity loans and mortgages, DOE also accounted for the fact that interest on both such loans is tax deductible. This rate corresponds to the interest rate after deduction of mortgage interest for income tax purposes and after adjusting for inflation. The specific inflation rates vary by SCF year, while the marginal tax rates vary by SCF year and income bin as shown in Table

[g] Fisher formula is given by: Real Interest Rate = [(1 + Nominal Interest Rate) / (1 + Inflation Rate)] – 1. Note that for this analysis DOE used a minimum real effective debt interest rate of 0 percent.

8.3.5. For example, a 6 percent nominal mortgage rate has an effective nominal rate of 5.5 percent for a household at the 25 percent marginal tax rate. When adjusted for an inflation rate of 2 percent, the effective real rate becomes 2.45 percent.

Table 8.3.5 Data Used to Calculate Real Effective Household Debt Rates

Year	Inflation Rate (%)	Applicable Marginal Tax Rate by Income Group (%)					
		1	2	3	4	5	6
1995	2.81	15.0	15.0	15.0	28.0	28.0	39.6
1998	1.55	15.0	15.0	15.0	28.0	28.0	39.6
2001	2.83	10.0	15.0	15.0	27.5	27.5	39.1
2004	2.68	10.0	15.0	15.0	25.0	25.0	35.0
2007	2.85	10.0	15.0	15.0	25.0	25.0	35.0
2010	1.64	10.0	15.0	15.0	25.0	25.0	35.0
2013	1.46	10.0	15.0	15.0	25.0	25.0	37.3
2016	1.26	10.0	15.0	15.0	25.0	25.0	37.3
2019	1.81	10.0	12.0	12.0	22.0	22.0	36.0

Table 8.3.6 shows the household-weighted average effective real rates in each year and the mean rate across years. Because the interest rates for each type of household debt reflect economic conditions throughout numerous years and various phases of economic growth and recession, they are expected to be representative of rates in effect in 2029.

Table 8.3.6 Average Real Effective Interest Rates for Household Debt (%)

Type of Debt	Income Group						
	1	2	3	4	5	6	All
Mortgage	4.09	3.74	3.60	2.92	2.79	2.19	3.18
Home equity loan	4.29	4.34	3.86	3.24	3.11	2.45	3.35
Credit card	9.80	11.02	11.15	11.26	10.90	10.11	10.64
Other installment loan	6.14	7.09	5.98	5.33	4.54	4.42	6.10
Other line of credit	3.73	3.67	6.23	5.47	4.89	5.33	4.97
Other residential loan	6.53	6.41	5.22	4.96	4.33	3.99	5.32

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016, and 2019.

8.3.5.4 Rates for Types of Assets

No similar rate data are available from the SCF for classes of assets, so DOE derived asset interest rates from various sources of national historical data (1991-2020). The rates for stocks are the annual returns on the Standard and Poor's 500 for 1991–2020.[7] The interest rates associated with AAA corporate bonds were collected from Moody's time-series data for 1991–2020.[8] Rates on Certificates of Deposit (CDs) accounts came from Cost of Savings Index (COSI) data covering 1991–2020.[9,h] The interest rates associated with state and local bonds (20-bond municipal bonds) were collected from Federal Reserve Board economic data time-series for 1991–2020.[14,i] The interest rates associated with treasury bills (30-Year treasury constant maturity rate) were collected from Federal Reserve Board economic data time-series for 1991–2020.[15,j] Rates for money market accounts are based on three-month money market account rates reported by Organization for Economic Cooperation and Development (OECD) from 1991–2020.[17] Rates for savings accounts are assumed to be half the average real money market rate. Rates for mutual funds are a weighted average of the stock rates and the bond rates.[k] DOE adjusted the nominal rates to real rates using the annual inflation rate in each year (see appendix 8C). In addition, DOE adjusted the nominal rates to real effective rates by accounting for the fact that interest on such equity types is taxable. The capital gains marginal tax rate varies for each household based on income as shown in Table 8.3.7.

Table 8.3.7 Average Capital Gains Marginal Tax Rate by Income Group (%)

Year	Income Group					
	1	2	3	4	5	6
1995	12.5	12.5	12.5	28.0	28.0	33.8
1998	12.5	12.5	12.5	24.0	24.0	29.8
2001	7.5	10.0	15.0	21.3	21.3	27.1
2004	7.5	10.0	15.0	21.3	21.3	27.1
2007	7.5	10.0	15.0	20.0	20.0	25.0
2010	5.0	7.5	15.0	20.0	20.0	25.0
2013	5.0	7.5	15.0	20.0	20.0	27.4
2016	5.0	7.5	15.0	20.0	20.0	27.4
2019	5.0	6.0	6.0	18.5	18.5	26.8

Average real effective interest rates for the classes of household assets are listed in Table 8.3.8. Because the interest and return rates for each type of asset reflect economic conditions

[h] The Wells COSI is based on the interest rates that the depository subsidiaries of Wells Fargo & Company pay to individuals on certificates of deposit (CDs), also known as personal time deposits. Wells Fargo COSI started in November 2009.[10] From July 2007 to October 2009 the index was known as Wachovia COSI[11] and from January 1984 to July 2007 the index was known as GDW (or World Savings) COSI.[12,13]

[i] This index was discontinued in 2016. To calculate the 2017 and after values, DOE compared 1981-2020 data for 30-Year Treasury Constant Maturity Rate[15] and Moody's AAA Corporate Bond Yield[8] to the 20-Bond Municipal Bond Index data.[14]

[j] From 2003-2005 there are no data. For 2003-2005, DOE used 20-Year Treasury Constant Maturity Rate.[16]

[k] SCF reports what type of mutual funds the household has (e.g. stock mutual fund, savings bond mutual fund, etc.). For mutual funds with a mixture of stocks and bonds, the mutual fund interest rate is a weighted average of the stock rates (two-thirds weight) and the savings bond rates (one-third weight).

throughout numerous years, they are expected to be representative of rates that may be in effect in the compliance year. The average nominal interest rates and the distribution of real interest rates by year are shown in appendix 8C.

Table 8.3.8 Average Real Interest Rates for Household Assets (%)

Equity Type	Income Group						
	1	**2**	**3**	**4**	**5**	**6**	**All**
Savings accounts	0.24	0.23	0.22	0.20	0.20	0.19	0.22
Money market accounts	0.48	0.47	0.45	0.41	0.41	0.37	0.43
Certificate of deposit	0.76	0.74	0.71	0.64	0.64	0.59	0.71
Treasury Bills (T-bills)	2.25	2.21	2.12	1.93	1.93	1.78	2.08
State/Local bonds	1.86	2.05	1.96	1.78	1.78	1.64	1.77
AAA Corporate Bonds	2.30	2.33	2.71	2.59	2.49	2.38	2.49
Stocks (S&P 500)	8.84	8.67	8.27	7.51	7.51	6.91	7.76
Mutual funds	7.31	7.37	7.13	6.38	6.46	5.67	6.52

8.3.5.5 Discount Rate Calculation and Summary

Using the asset and debt data discussed above, DOE calculated discount rate distributions for each income group as follows. First, DOE calculated the discount rate for each consumer in each of the versions of the *SCF*, using the following formula:

$$DR_i = \sum_j Share_{i,j} \times Rate_{i,j}$$

Where:

DR_i = discount rate for consumer i,
$Share_{i,j}$ = share of asset or debt type j for consumer i, and
$Rate_{i,j}$ = real interest rate or rate of return of asset or debt type j for consumer i.

The rate for each debt type is drawn from the SCF data for each household. The rate for each asset type is drawn from the distributions described above.

Once the real discount rate was estimated for each consumer, DOE compiled the distribution of discount rates in each survey by income group by calculating the proportion of consumers with discount rates in bins of 1 percent increments, ranging from 0-1 percent at the low end to 30 percent and greater at the high end. Giving equal weight to each survey, DOE compiled the overall distribution of discount rates.

Table 8.3.9 presents the average real effective discount rate and its standard deviation for each of the six income groups. To account for variation among households, DOE sampled a rate for each RECS household from the distributions for the appropriate income group. (RECS provides household income data.) Appendix 8C presents the full probability distributions for each income group that DOE used in the LCC and PBP analysis.

Table 8.3.9 Average Real Effective Discount Rates

Income Group	Discount Rate (%)
1	4.76
2	4.99
3	4.54
4	3.84
5	3.47
6	3.23
Overall Average	4.29

Source: Board of Governors of the Federal Reserve System, Survey of Consumer Finances (1995 – 2019)

8.4 ENERGY EFFICIENCY DISTRIBUTIONS

To estimate the percentage of consumers who would be affected by a potential standard at any of the considered efficiency levels, DOE first develops a distribution of efficiencies for products that consumers purchase under the no-new-standards case.

In the October 2016 MREF Direct Final Rule (81 FR 75194), DOE estimated the current distribution of product efficiencies using surveys of product owners;[18] information from the Association of Home Appliance Manufacturers (AHAM) (Docket No. EERE-2011-BT-STD-0043-0106), the DOE CCMS database,[19] the CEC database,[20] the NRCan database,[21] manufacturer and retailer websites, feedback from manufacturers, and DOE's internal testing.

For this preliminary analysis, DOE estimated the no-new standards case efficiency distribution based on model counts from DOE's CCMS database.[19] Models in the database were categorized by capacity and assigned an efficiency level based on reported energy use. Due to the lack of market shares data, DOE assumed that the distribution of models was equivalent to the distribution of products sold. DOE projected that the current distribution of product efficiencies would remain constant in 2029 in the no-new-standards case.

Table 8.4.1 shows the no-new-standards case efficiency distribution in the compliance year for the evaluated product classes.

Table 8.4.1 Efficiency Distributions for the No-New-Standards Case in the Compliance Year

Product Class	Total Adjusted Volume (cu. ft.)	2029 Market Share (%)						
		EL 0	EL 1	EL 2	EL 3	EL 4	EL 5	Total*
Cooler-FC	3.1	81.7	9.6	8.7	0.0	0.0	0.0	100.0
	5.1	75.5	14.3	9.8	0.3	0.0	0.0	100.0
Cooler-F	15.3	64.6	24.8	9.7	0.9	0.0	0.0	100.0
C-13A	5.1	77.8	6.7	13.3	0.0	2.2		100.0
C-3A	21	100.0	0.0	0.0	0.0	0.0		100.0
C-9	29.3	0.0	100.0	0.0	0.0	0.0		100.0

* The total may not sum to 100% due to rounding.

Using the projected distribution of efficiencies for MREFs, DOE randomly assigned a product efficiency to each household drawn from the consumer samples. If a consumer is assigned a product efficiency that is greater than or equal to the efficiency under consideration, the consumer would not be affected by a standard at that efficiency level.

8.5 LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

The LCC calculations were performed for each of the 10,000 consumers in the sample of consumers established for each product class. Each LCC calculation sampled inputs from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

For the set of the sample consumers for each product class, DOE calculated the average installed cost, first year's operating cost, lifetime operating cost, and LCC for each EL. These averages are calculated assuming that all of the sample purchasers purchase a product at each EL. This allows the installation costs, operating costs, and LCCs for each EL to be compared under the same conditions, across a variety of sample purchasers. DOE used these average values to calculate the PBP for each EL, relative to the baseline EL.

DOE first assigned MREFs to consumers using the efficiency distribution in the no-new-standards case. DOE calculated the LCC and PBP for all consumers as if each were to purchase a new MREF in the expected year of compliance with amended standards. For any given efficiency level, DOE measures the change in LCC relative to the LCC in the no-new-standards case, which reflects the estimated efficiency distribution of MREFs in the absence of new or amended energy conservation standards.

The following sections present the key LCC and PBP findings, as well as figures that illustrate the range of LCC and PBP effects among a sample of consumers. A consumer is considered to have received a net LCC cost if the purchaser had negative LCC savings at the EL being analyzed. DOE presents the average LCC savings for affected consumers, which includes only consumers with non-zero LCC savings due to the standard.

8.5.1 Summary of Results

Table 8.5.1 LCC and PBP Results by Efficiency level for Cooler-FC

Efficiency Level	Average Costs (*2020$*)				Simple PBP (*years*)	Average Lifetime (*years*)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Baseline	526.9	27.9	238.3	765.3	--	10.3
1	534.7	23.3	198.5	733.2	1.7	10.3
2	590.5	20.6	176.0	766.5	8.7	10.3
3	686.1	16.2	138.0	824.1	13.6	10.3
4	789.2	15.0	127.5	916.7	20.3	10.3
5	819.8	14.6	124.5	944.3	22.0	10.3

Note: The results for each EL represent the average value if all purchasers in the sample use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8.5.2 Average LCC Savings for Cooler-FC

Efficiency Level	Average LCC Savings* *(2020$)*	% of Consumers that Experience Net Cost
1	39.67	1%
2	-1.32	56%
3	-60.59	75%
4	-152.02	93%
5	-179.73	94%

* The calculation considers only affected consumers. It excludes purchasers whose purchasing decision would not change under a standard set at the corresponding EL, i.e., those with zero LCC savings.

Table 8.5.3 LCC and PBP Results by Efficiency Level for Cooler-F

Efficiency Level	Average Costs (*2020$*)				Simple PBP (*years*)	Average Lifetime (*years*)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Baseline	1755.0	42.8	551.8	2306.8	--	17.4
1	1775.9	40.0	515.2	2291.1	7.3	17.4
2	1850.7	36.0	464.2	2314.8	14.1	17.4
3	1942.1	31.6	407.4	2349.6	16.8	17.4
4	2257.8	29.4	378.8	2636.6	37.6	17.4
5	2371.9	27.6	355.9	2727.8	40.7	17.4

Note: The results for each EL represent the average value if all purchasers in the sample use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8.5.4 Average LCC Savings for Cooler-F

Efficiency Level	Average LCC Savings* *(2020$)*	% of Consumers that Experience Net Cost
1	24.59	19%
2	-8.95	62%
3	-43.13	76%
4	-329.75	97%
5	-420.99	98%

* The calculation considers only affected consumers. It excludes purchasers whose purchasing decision would not change under a standard set at the corresponding EL, i.e., those with zero LCC savings.

Table 8.5.5 LCC and PBP Results by Efficiency level for C-13A

Efficiency Level	Average Costs (*2020$*)				Simple PBP (*years*)	Average Lifetime (*years*)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Baseline	1872.3	34.4	292.5	2164.8	--	10.3
1	1875.7	31.7	269.5	2145.1	1.2	10.3
2	1879.6	29.0	246.8	2126.4	1.4	10.3
3	2010.8	27.3	232.1	2242.9	19.6	10.3
4	2115.1	26.3	223.4	2338.4	29.9	10.3

Note: The results for each EL represent the average value if all purchasers in the sample use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8.5.6 Average LCC Savings for C-13A

Efficiency Level	Average LCC Savings* *(2020$)*	% of Consumers that Experience Net Cost
1	25.45	0%
2	45.66	1%
3	-79.94	90%
4	-177.71	96%

* The calculation considers only affected consumers. It excludes purchasers whose purchasing decision would not change under a standard set at the corresponding EL, i.e., those with zero LCC savings.

Table 8.5.7 LCC and PBP Results by Efficiency Level for C-3A

Efficiency Level	Average Costs (*2020$*)				Simple PBP (*years*)	Average Lifetime (*years*)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Baseline	4508.1	36.4	470.9	4979.0	--	17.4
1	4542.7	32.8	424.3	4967.0	9.6	17.4
2	4546.4	29.9	387.1	4933.5	5.9	17.4
3	4624.5	28.9	373.1	4997.6	15.5	17.4
4	4863.9	27.4	354.5	5218.4	39.7	17.4

Note: The results for each EL represent the average value if all purchasers in the sample use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8.5.8 Average LCC Savings for C-3A

Efficiency Level	Average LCC Savings* *(2020$)*	% of Consumers that Experience Net Cost
1	12.03	47%
2	45.54	18%
3	-18.62	74%
4	-239.38	98%

* The calculation considers only affected consumers. It excludes purchasers whose purchasing decision would not change under a standard set at the corresponding EL, i.e., those with zero LCC savings.

Table 8.5.9 LCC and PBP Results by Efficiency level for C-9

Efficiency Level	Average Costs (*2020$*)				Simple PBP (*years*)	Average Lifetime (*years*)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Baseline	4796.0	45.2	583.3	5379.3	--	17.4
1	4796.0	45.2	583.3	5379.3	0.0	17.4
2	4803.1	40.3	519.4	5322.5	1.4	17.4
3	4886.0	37.3	481.1	5367.1	11.4	17.4
4	5138.2	34.9	449.1	5587.3	33.0	17.4

Note: The results for each EL represent the average value if all purchasers in the sample use products with that efficiency level. The PBP is measured relative to the baseline product.

Table 8.5.10 Average LCC Savings for C-9

Efficiency Level	Average LCC Savings* *(2020$)*	% of Consumers that Experience Net Cost
1	N/A**	0%
2	56.80	0%
3	12.24	58%
4	-207.99	96%

* The calculation considers only affected consumers. It excludes purchasers whose purchasing decision would not change under a standard set at the corresponding EL, i.e., those with zero LCC savings.
** There are no affected consumers at EL1

8.5.2 Range of LCC Impacts

Figure 8.5.1 through Figure 8.5.5 show the range of LCC savings for all candidate standard levels (simply "standard levels") considered for each MREF product class. For each efficiency level, the left and right edges of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of consumers have LCC savings in excess of that value. The "whiskers" at the bottom and the top of the box indicate the 5th and 95th percentiles. The small black circle shows the average LCC savings for each efficiency level.

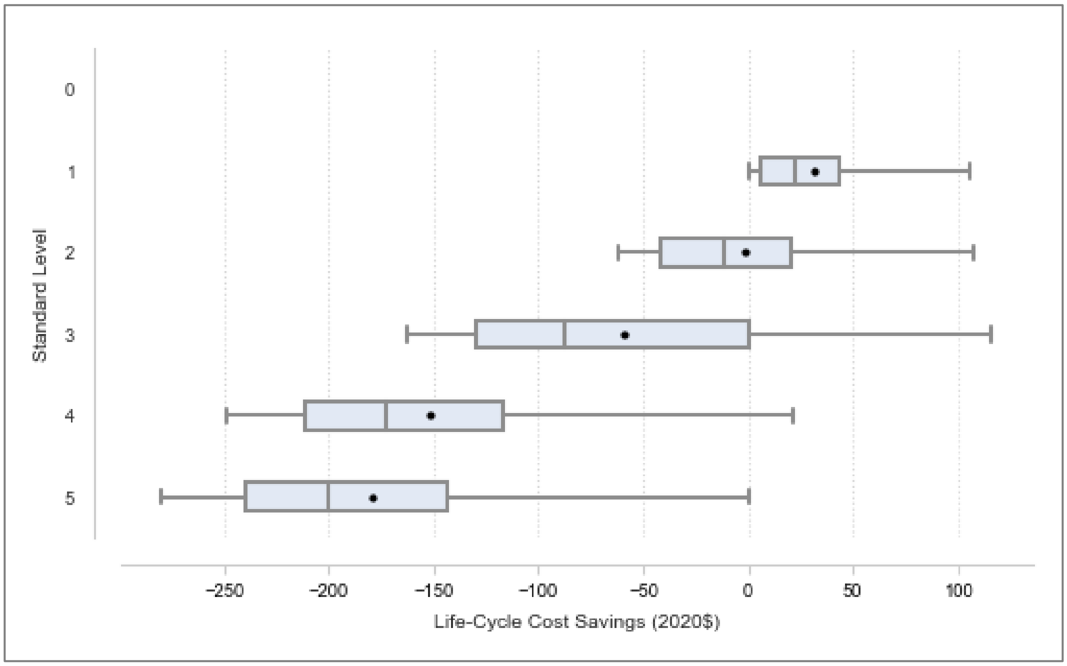

Figure 8.5.1 Distribution of LCC Cost Savings: Cooler-FC

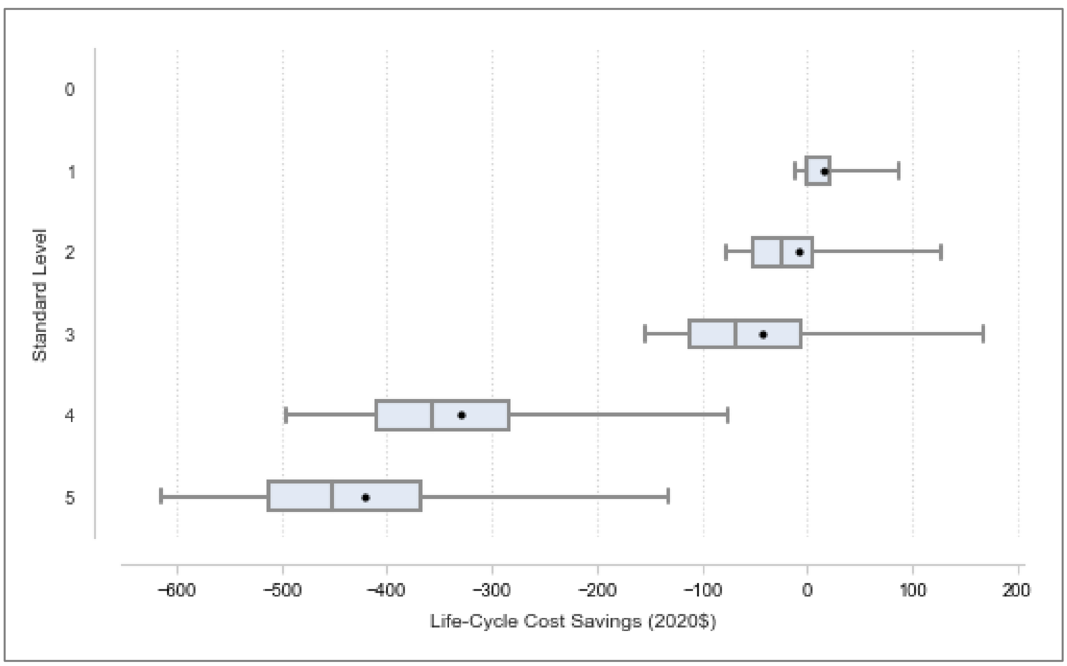

Figure 8.5.2 Distribution of LCC Cost Savings: Cooler-F

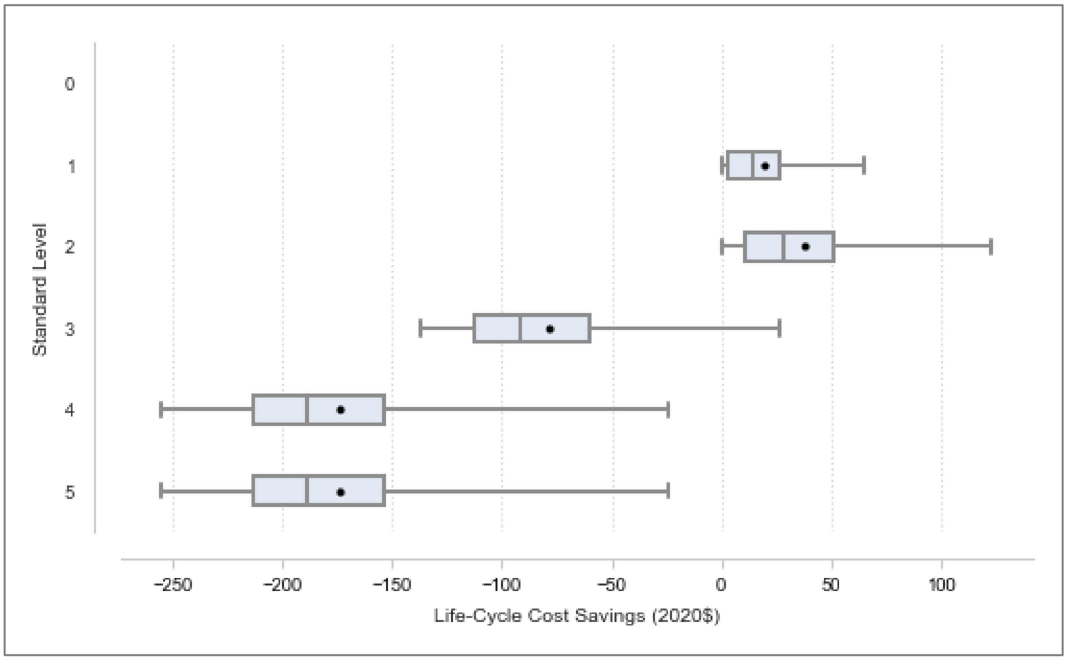

Figure 8.5.3 Distribution of LCC Cost Savings: C-13A

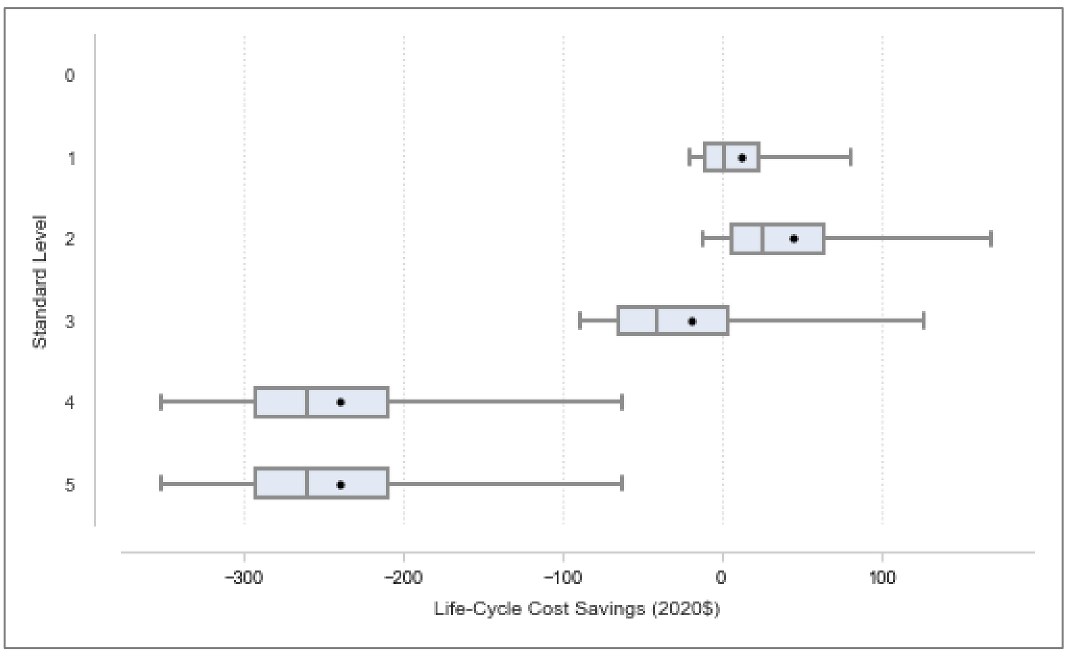

Figure 8.5.4 Distribution of LCC Cost Savings: C-3A

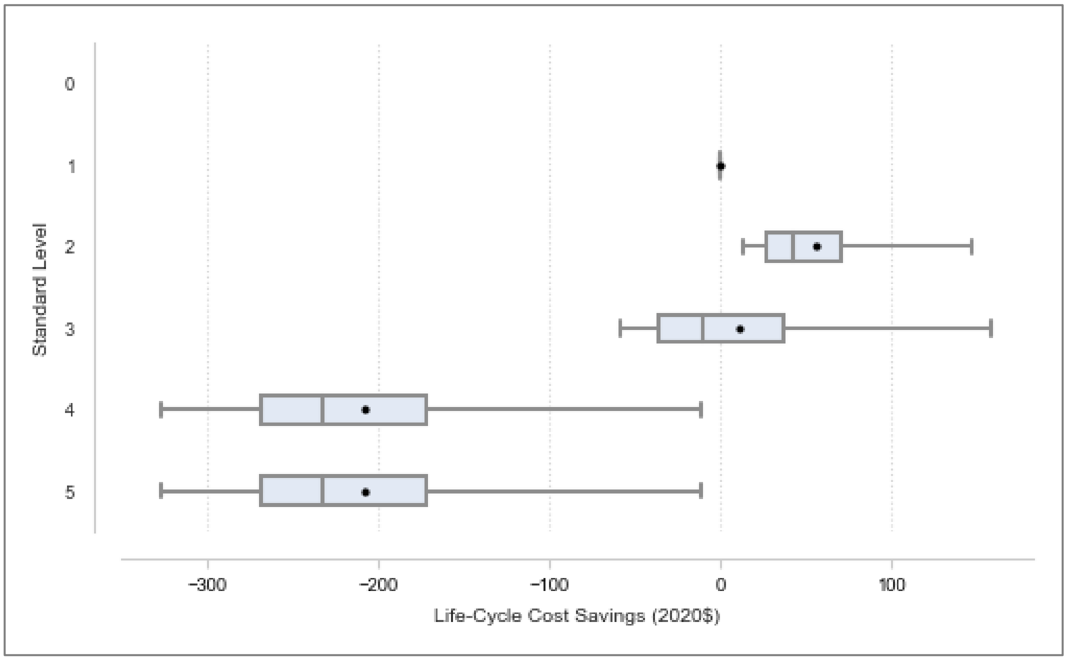

Figure 8.5.5 Distribution of LCC Cost Savings: C-9

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CHAPTER 9. SHIPMENTS ANALYSIS

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CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

Projections of product shipments are a necessary input for calculating national energy savings ("NES") and net present value ("NPV") of potential new or amended energy efficiency standards. Shipments also are a necessary input to the manufacturer impact analysis. This chapter describes DOE's method and results of projecting annual shipments for miscellaneous refrigeration products ("MREFs").

DOE defined two MREF product categories (coolers, and combination cooler refrigeration products) and developed models to estimate shipments for each category. DOE then used various data and assumptions to disaggregate total MREF shipments into the product classes considered in this rulemaking.

The shipments model was developed as a part of the Excel spreadsheet used for the national impacts analysis ("NIA"). Appendix 10A of this technical support document ("TSD") describes how to access the NIA workbook and provides basic instructions for its use.

The rest of this chapter is organized as follows: Section 9.2 presents an overview of the shipments model and section 9.3 describes the data inputs and analysis of market segments, as well as the shipments projections.

9.2 SHIPMENTS MODEL OVERVIEW

Stock accounting provides an estimate of the age distribution of product stocks for all years, using product shipments, a retirement function, and initial product stock as inputs. The age distribution of product stocks is a key input to both the NES and NPV calculations, because the operating costs for any year depend on the age distribution of the stock. Older, less efficient units may have higher operating costs, while younger, more-efficient units have lower operating costs.

As units are added to the stock, some of the older ones retire and exit the stock. To estimate future shipments, DOE developed a series of equations that define the dynamics and accounting of stocks. For new units see Eq. 9.1:

$$\mathrm{Stock}(\mathrm{y}, \mathrm{age} = 1) = Ship(y - 1)$$

Eq. 9.1

Where:

Stock(y, age) =	number of units of a particular age in stock in year y,
y =	year for which the stock is being estimated, and

Ship (y) = number of units purchased in year *y*.

The above equation states that the number of one-year-old units is simply equal to the number of new units purchased the previous year. Slightly more complicated equations, such as the following equation, describe how the model accounts for the existing stock of units.

$$\mathrm{Stock}(\mathrm{y}+1, \mathrm{age}+1) = Stock(y, age) \times [1 - P_{ret}(age)]$$

Eq. 9.2

In this equation, as the year is incremented from y to *y+1*, the age is also incremented from *age* to *age+1*. Over time, a fraction of the stock is removed; that fraction is determined by a retirement probability function, $prob_{Rtr}(age)$.

The affected stock is the in-service stock of the product that is affected by a standard level. The affected stock consists of those in-service units that are purchased in or after the year a standard takes effect, as described by the following equation.

$$\mathrm{Stock}_{aff}(\mathrm{y}) = Ship(y) + \sum_{age=1}^{y-Std_{yr}} Stock\ (y, age)$$

Where:

$\mathrm{Stock}_{aff}(\mathrm{y})$	=	affected stock of units of all vintages that are operational in year *y*,
$Ship(y)$	=	shipments in year *y*,
Std_yr	=	compliance date of standard, and
$\sum_{age=1}^{y-Std_{yr}} Stock\ (y, age)$	=	stock of units of all vintages shipped after the standards year that are operational in year y.

For the current analysis, DOE assumed that any new energy efficiency standards for MREFs would require compliance in 2029. Thus, all appliances purchased starting in 2029 are affected by the standard level. DOE's analysis considers shipments over a 30-year period, in this case from 2029 through 2058. Due to insufficient historical price and shipment data for MREFs, DOE currently does not consider the impact of higher purchase prices resulting from higher efficiency standards on shipments. Thus, the standards case shipments are assumed to be the same as the no-new-standards case for each of the analyzed product classes.

9.3 DATA INPUTS AND PROJECTED SHIPMENTS

As discussed in chapter 3 of this TSD, data on historical MREF shipments are limited. For coolers, DOE used the saturation rate derived from survey results to estimate the national stock of in-service appliances. DOE then estimated shipments by combining the estimate of total stocks with product lifetime estimates described in chapter 8 of this TSD. For combination cooler refrigeration products, DOE used feedback from manufacturers and a database of available models.

In response to the December 2020 Early Assessment RFI, AHAM collected and provided MREF shipments from AHAM members from 2016 through 2020. AHAM noted that the provided shipments did not include shipments from the full industry but stated that they accounted for a significant portion of the MREF market. Based on these data, AHAM stated that MREF shipments are significantly lower than those estimated under the October 2016 Direct Final Rule. (AHAM, No. 3, p. 2).

DOE reviewed the AHAM-submitted shipments data as well as other available data sources to evaluate shipments for MREFs. DOE notes that AHAM did not specify whether the AHAM shipments data included the entirety of the AHAM membership, or whether these data reflect shipments from a subset of AHAM members. To estimate the fraction of AHAM-member shipments compared to the rest of the industry, DOE reviewed its CCMS database and estimated that for freestanding compact and freestanding coolers (which make up the vast majority of the MREF market), approximately 25 percent of available models correspond to AHAM members. DOE also reviewed the TraQline wine chiller data and estimated that approximately 23 percent of wine chiller consumers (over 10 years of historical data) purchased MREFs made by AHAM members.

Based on these market share estimates, and given the uncertainty associated with the AHAM data, for this preliminary analysis DOE has decided to retain the overall shipments methodology and assumptions of the October 2016 Direct Final Rule and the resulting MREF shipments. DOE is requesting comment on this approach and data on the overall shipments for MREFs.

9.3.1 Product-Specific Models

This section describes the models used to forecast shipments of the two MREF categories, coolers and combination cooler products. For each model, the following sections describe the sources of data used to estimate shipments, the approach for disaggregating total shipments into product classes, and the projected shipments results.

9.3.1.1 Coolers

Given the limited available data sources on historical shipments of coolers, DOE used the same approach as described in the October 2016 Direct Final Rule (81 FR 75194) to estimate cooler shipments. An overall cooler penetration rate of 13.3 percent in the U.S. household was determined based on online surveys.[1,2] DOE found no historical data on household penetration or shipments of these products, and thus assumed that it would remain the same projecting forward to 2058. DOE multiplied the estimated penetration by the total number of households estimate from *AEO 2021* forecasts to determine the current stock of coolers in U.S. households.

DOE then determined the number of new shipments by dividing the total stock by the mean product lifetime as discussed in chapter 8. DOE assumed that this ratio would remain the same projecting forward to 2058.

DOE disaggregated the shipments into the different product classes based on the same product class market shares developed in the October 2016 Direct Final Rule. Table 9.3.1 presents the estimated market shares for disaggregating modeled shipments of coolers. Because a reliable method for projecting market share changes was unavailable, DOE used these estimated market shares throughout the forecast period.

Table 9.3.1 Product Class Market Shares for Coolers

Product Class	Market share (%)*
Freestanding Compact	96.7%
Built-in Compact	0.4%
Freestanding	2.4%
Built-in	0.5%

*Total may not sum to 100 due to rounding

Figure 9.3.1 through Figure 9.3.3 show the projected shipments of coolers. For all product classes the shipments show an increase over time. This increase is in line with the estimated increase in the number of U.S. households from *AEO 2021*.

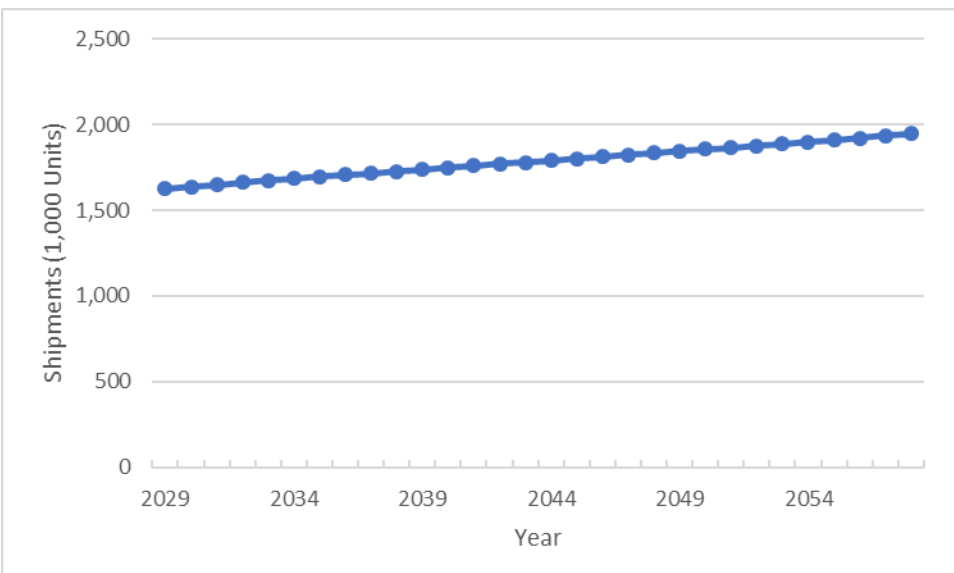

Figure 9.3.1 Freestanding compact cooler shipments projections to 2058

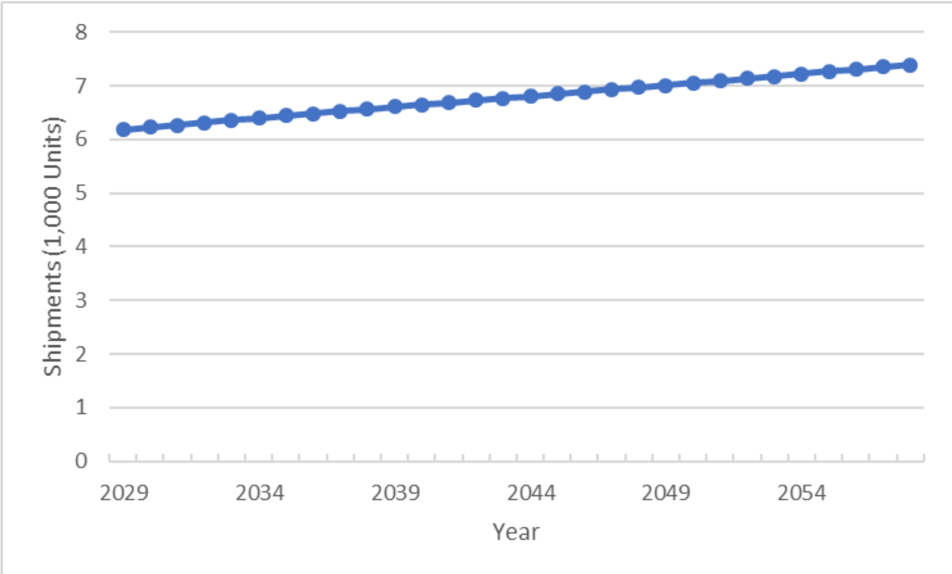

Figure 9.3.2 Built-in compact cooler shipments projections to 2058

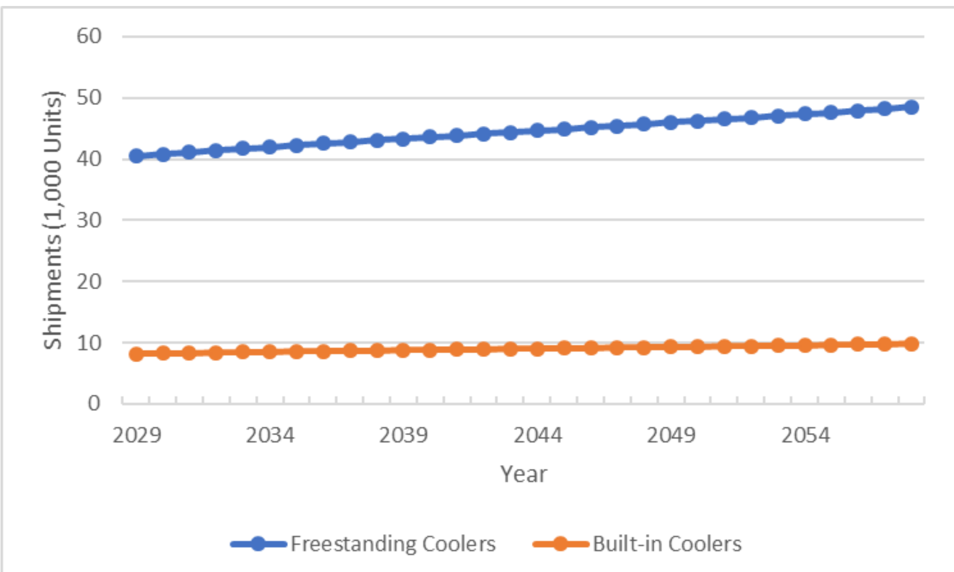

Figure 9.3.3 Full size cooler shipments projections to 2058

9.3.1.2 Combination Cooler Refrigeration Products

DOE estimated total shipments of combination cooler refrigeration products in 2014 to be 36,000 units, based on feedback from manufacturers. DOE assumed sales would increase in line with the increase in the number of households.

DOE disaggregated combination cooler refrigeration products shipments into product classes by assuming that the distribution of shipments is proportional to the distribution of available models. DOE identified 45 combination cooler refrigeration products from DOE's Compliance Certification Database[3], covering three product classes. Table 9.3.2 shows the market share attributed to each of the combination cooler refrigeration product classes. The projected shipments are shown in Figure 9.3.4.

Table 9.3.2 Product Class Market Shares for Combination Cooler Refrigeration Products

Product Class	Market share (%)*
C-3A	0
C-3A-BI	0
C-9	2.2
C-9-BI	0
C-13A	93.3
C-13A-BI	4.4

*Total may not sum to 100 due to rounding

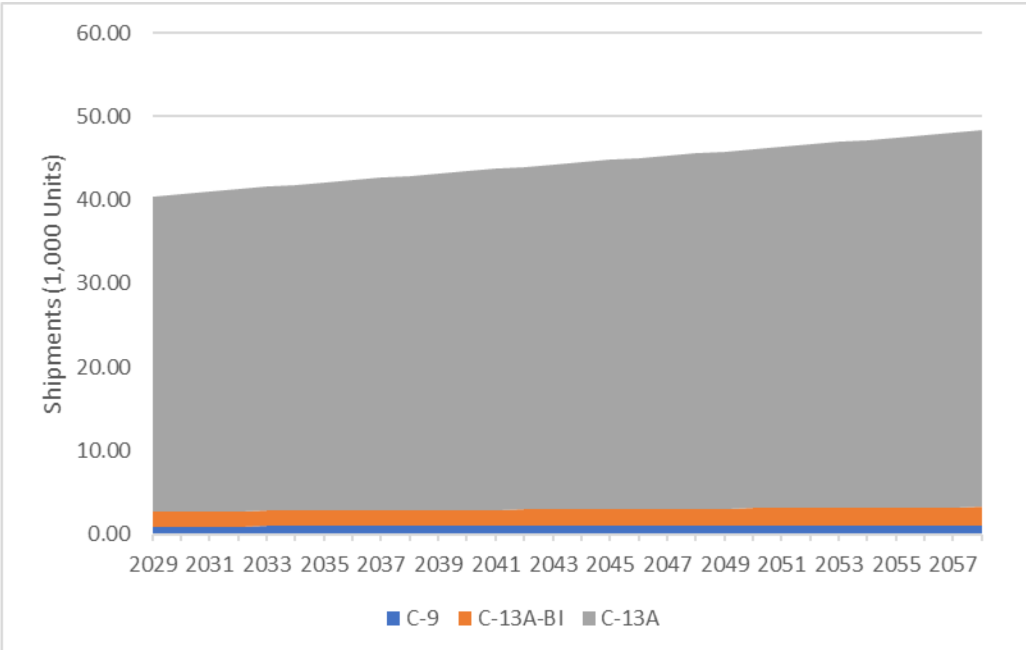

Figure 9.3.4 Projected shipments of combination cooler refrigeration products

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CHAPTER 10. NATIONAL IMPACT ANALYSIS

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CHAPTER 10. NATIONAL IMPACT ANALYSIS

10.1 INTRODUCTION

This chapter describes the methods the U.S. Department of Energy ("DOE") used to conduct a national impact analysis ("NIA") of potential energy efficiency standard levels for miscellaneous refrigeration products ("MREFs"), and the results of the analysis. For each potential standard level, DOE evaluated the following impacts: (1) national energy savings ("NES"), (2) monetary value of the energy savings for consumers of MREFs, (3) increased total installed costs, and (4) the net present value ("NPV"), which is the difference between the savings in operating costs and the increase in total installed costs.

DOE determined the NES and NPV for all the efficiency levels ("ELs") considered for MREFs. DOE performed all calculations using a Microsoft Excel spreadsheet model, which is accessible at www.regulations.gov/docket/EERE-2011-BT-STD-0043. The spreadsheet combines the calculations for determining the NES and NPV for each considered EL with input from the appropriate shipments model. Details and instructions for using the NIA model are provided in appendix 10A of this technical support document ("TSD").

The NIA calculation starts with the shipments model. Chapter 9 of this TSD provides a detailed description of the shipments model that DOE used to project future purchases of MREFs.

DOE analyzed three product classes as described in chapter 5 of this TSD: Freestanding Compact Coolers, Freestanding Coolers, and Combination Cooler Refrigeration Product class C-13A. DOE also estimated NES and NPV for two more product classes for which it constructed cost-efficiency curves (C-3A and C-9).

The analysis is described more fully in subsequent sections. The descriptions include overviews of how DOE performed each model's calculations and summaries of the major inputs. Table 10.1.1 summarizes inputs to the NIA.

Table 10.1.1 Inputs to Calculating National Energy Savings and Net Present Value

Input	Data Description
Shipments	Annual shipments from shipments model (chapter 9).
Compliance date of standard	2029
Analysis period	For products shipped between 2029 through 2058
Energy efficiency in no-new-standards case	Assumed Constant throughout the analysis period
Energy efficiency in standards cases	Roll-up scenario
Annual unit energy consumption	Annual weighted-average values as a function of shipments-weighted unit energy consumption (UEC).
Total installed cost per unit	Annual weighted-average values as a function of efficiency distribution.

Input	Data Description
Energy cost per unit	Annual weighted-average values as a function of the annual UEC and energy prices (see chapter 8 for energy prices).
Trend in energy prices	Based on Energy Information Administration's (EIA's) Annual Energy Outlook (AEO) 2021 Reference case (see chapter 8).
Energy site-to-primary factor	A time-series conversion factor that accounts for energy used to generate electricity.
Full-fuel-cycle multiplier	Developed to include the energy consumed in extracting, processing, and transporting or distributing primary fuels.
Discount rate	3 percent and 7 percent.
Present year	Future expenses are discounted to 2020.

10.1.1 Trial Standard Levels

Table 10.1.2 presents the Trial Standard Levels (TSLs) and the corresponding efficiency levels for the analyzed product classes. TSL 5 represents the maximum technologically feasible ("max-tech") energy efficiency for all product classes.

Table 10.1.2 Mapping of ELs to TSLs by Product Class

Product Class		TSL				
		1	2	3	4	5
Cooler-FC	EL	1	2	3	4	5
Cooler-F		1	2	3	4	5
C-13A		1	2	3	4	4
C-3A		1	2	3	4	4
C-9		1	2	3	4	4

10.2 PROJECTED EFFICIENCY DISTRIBUTION

The trend in forecasted energy efficiency is a key factor in estimating NES and NPV for the no-new-standards case and each potential standards case. For calculating the NES, per-unit average annual energy consumption is a direct function of product energy efficiency. For the NPV, both the per-unit total installed cost and the per-unit annual operating cost are dependent on product energy efficiency.

In this preliminary analysis, DOE estimated the no-new standards case efficiency distribution based on model counts from DOE's Compliance Certification Database[1]. Models in the database were categorized by capacity and assigned an efficiency level based on reported energy use. DOE assumed the current efficiency distribution would be representative of the efficiency distribution in 2029 in the no-new-standards case. See chapter 8 of this TSD for details.

In the no-new-standards case, DOE assumed the efficiency distribution would remain fixed over the course of the analysis period. For standards cases, DOE assumed the market share for efficiency levels that did not meet the standard would "roll-up" to the minimum level that meets the standard in the assumed compliance year (2029). DOE also assumed that all product efficiencies in the no-new-standard case that exceeded the standard would not be affected. Market shares across efficiency levels (in the no standards case and the standards cases) were assumed to be fixed following the implementation of a standard.

10.3 NATIONAL ENERGY SAVINGS

DOE calculated the NES associated with the difference between the no-new-standards case and each standards case for MREFs. DOE's analysis considers lifetime energy use of products shipped in the 30-year period beginning in the compliance year—in this case, 2029. The analysis period ends when all of the products shipped in the 30-year period are retired from the stock.

DOE calculates NES expressed as:

- Primary energy: Accounts for the energy used to generate electricity,
- Full-fuel-cycle (FFC) energy: Accounts for the energy consumed in extracting, processing, and transporting or distributing primary fuels.

10.3.1 Definition

DOE calculates annual NES for a given year as the difference between the national annual energy consumption (AEC) in a no-new-standards case and a standards case. Cumulative energy savings are the sum of annual NES throughout the analysis period.

In determining national AEC, DOE first calculates AEC at the site. DOE calculates the national annual site energy consumption by multiplying the number or stock of the product (by vintage) by its unit energy consumption (also by vintage). National annual energy consumption is calculated using the following equation:

$$AEC\text{-}s_y = \sum STOCK_V \times UEC_V$$

Where:

$AEC\text{-}s$ = annual national site energy consumption in quadrillion British thermal units (quads),
$STOCK_V$ = stock of product of vintage V that survive in the year for which DOE calculates the AEC,
UEC_V = annual energy consumption per unit of MREFs,
V = year in which the product was purchased as a new unit,
y = year in the forecast.

The stock of a product depends on annual shipments and the lifetime of the product. As described in chapter 9 of this TSD, DOE projected product shipments under the no-new-standards case and standards cases.

DOE applies conversion factors to site energy to calculate primary AEC and to primary energy to calculate FFC AEC.

10.3.2 Annual Energy Consumption per Unit

DOE developed per-unit annual energy consumption as a function of product energy efficiency for MREFs (see chapter 7 of this TSD). DOE used the shipments-weighted energy efficiencies for the no-new-standards case and standards cases, along with the estimates of annual energy use by efficiency level, to estimate the shipments-weighted annual average per-unit energy use under the no-new-standards and standards cases. Table 10.3.1 and Table 10.3.2 show the values applied for the analyzed MREF product classes.

Table 10.3.1 Coolers: Annual Energy Use for No-New-Standards and Standards Cases

	No New Standards Case	**Standard at Efficiency Level:**				
		1	2	3	4	5
Freestanding Compact Coolers						
(kWh/year)	173.4	143.9	127.3	99.2	91.5	89.3
Freestanding Coolers						
(kWh/year)	263.2	245.5	220.8	193.5	179.6	168.6

Table 10.3.2 Combination Cooler Refrigeration Products: Annual Energy Use for No-New-Standards and Standards Cases

	No New Standards Case	**Standard at Efficiency Level:**				
		1	2	3	4	5
C-3A *(not directly analyzed)*						
(kWh/year)	226.4	203.7	185.6	178.8	169.8	169.8
C-9 *(not directly analyzed)*						
(kWh/year)	280.1	280.1	249.0	230.3	214.7	214.7
C-13A						
(kWh/year)	215.3	197.9	181.0	170.0	163.5	163.5

10.3.3 Shipments and Product Stock

The product stock in a given year is the number of products shipped from earlier years that survive in that year. The shipments model, which feeds into the NIA, tracks the number of units shipped each year. DOE assumes that products have an increasing probability of retiring as they age. The probability of survival as a function of years since purchase is called the survival function. Chapter 8 of this TSD provides additional details on the survival function that DOE used for MREFs.

10.3.4 Site-to-Primary Energy Conversion Factor

The site-to-primary energy conversion factor is a multiplicative factor used to convert site energy consumption into primary or source energy consumption, expressed in quads. For electricity from the grid, primary energy consumption is equal to the heat content of the fuels used to generate that electricity.[a] For natural gas and fuel oil, primary energy is equivalent to site energy.

DOE used annual conversion factors based on the version of the National Energy Modeling System (NEMS)[b] that corresponds to *AEO 2021*.[2] The factors are marginal values, which represent the response of the national power system to incremental changes in consumption. The conversion factors change over time in response to projected changes in generation sources (the types of power plants projected to provide electricity). Specific conversion factors were generated from NEMS for a number of end uses in each sector. Appendix 10B describes how DOE derived these factors.

Table 10.3.3 shows the conversion factors used for MREFs. DOE used the factors corresponding to refrigeration in the residential sector.

Table 10.3.3 Site-to-Primary Conversion Factors (MMBtu primary/MWh site) Used for MREFs

	2025	2030	2035	2040	2045	2050+
Residential						
Refrigeration	9.496	9.267	9.264	9.212	9.159	9.138

10.3.5 Full-Fuel-Cycle Multipliers

DOE uses an FFC multiplier to account for the energy consumed in extracting, processing, and transporting or distributing primary fuels, which are referred to as upstream activities. DOE developed FFC multipliers using data and projections generated for *AEO 2021*. *AEO 2021* provides extensive information about the energy system, including projections of future oil, natural gas, and coal supplies; energy use for oil and gas field and refinery operations; and fuel consumption and emissions related to electric power production. The information can be used to define a set of parameters that represent the energy intensity of energy production.

The method used to calculate FFC energy multipliers is described in appendix 10B of this TSD. The multipliers are applied to primary energy consumption. Table 10.3.4 shows the FFC energy multipliers for selected years.

Table 10.3.4 Full-Fuel-Cycle Energy Multipliers (based on *AEO 2021*)

	2025	2030	2035	2040	2045	2050+
Electricity	1.042	1.039	1.038	1.037	1.038	1.037

[a] For electricity sources such as nuclear energy and renewable energy, the primary energy is calculated using the convention used by EIA (see appendix 10B).

[b] For more information on NEMS, refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 2000*, DOE/EIA-0581(2000), March 2000. EIA approves use of the name NEMS to describe only an official version of the model with no modification to code or data.

10.4 NET PRESENT VALUE

10.4.1 Definition

The NPV is the value in the present of a time-series of costs and savings. The NPV is described by the equation:

$$NPV = PVS - PVC$$

Where:

PVS = present value of operating cost savings,[c] and
PVC = present value of increased total installed costs (purchase price and any installation costs).

DOE determines the PVS and PVC according to the following expressions.

$$PVS = \sum OCS_y \times DF_y$$

$$PVC = \sum TIC_y \times DF_y$$

Where:

OCS = total annual-savings in operating costs summed over vintages of the stock;
DF = discount factor in each year;
TIC = total annual increases in installed cost summed over vintages of the stock; and
y = year in the forecast.

DOE calculated the total annual consumer savings in operating costs by multiplying the number or stock of the product (by vintage) by its per-unit operating cost savings (also by vintage). DOE calculated the total annual increases in consumer product price by multiplying the number or shipments of the product (by vintage) by its per-unit increase in consumer cost (also by vintage). Total annual operating cost savings and total annual product installed cost increases are calculated by the following equations.

$$OCS_y = \sum STOCK_V \times UOCS_V$$

$$TIC_y = \sum SHIP_y \times UTIC_y$$

Where:
OCS_y = operating cost savings per unit in year y,
$STOCK_V$ = stock of products of vintage V that survive in the year for which DOE calculated annual energy consumption,
$UOCS_V$ = annual operating cost savings per unit of vintage V,
V = year in which the product was purchased as a new unit;
TIC_y = total increase in installed product cost in year y.

[c] The operating cost includes energy, water (if relevant), repair, and maintenance.

$SHIP_y$	=	shipments of the product in year *y*; and
$UTIC_y$	=	annual per-unit increase in installed product cost in year *y*.

DOE determined the total increased product cost for each year from 2029 to 2058. DOE determined the present value of operating cost savings for each year from 2029 to the year when all units purchased in 2058 are estimated to retire. DOE calculated installed cost and operating cost savings as the difference between a standards case and a no-new-standards case.

DOE developed a discount factor from the national discount rate and the number of years between the "present" (year to which the sum is being discounted) and the year in which the costs and savings occur.

10.4.2 Total Installed Cost

The per-unit total installed cost is a function of product energy efficiency. Therefore, DOE used the shipments-weighted efficiencies of the no-new-standards case and standards cases described in section 10.2, in combination with the total installed costs developed in chapter 8, to estimate the shipments-weighted average annual per-unit total installed cost under the various cases. Table 10.4.1 and Table 10.4.2 show the shipment-weighted average total installed costs for MREFs by product class in 2029 based on the efficiencies that correspond to the no-new-standards case and each standards case.

Table 10.4.1 Coolers: Total Installed Costs for No-New-Standards and Standards Cases

	No New Standards Case	Standard at Efficiency Level:				
		1	2	3	4	5
Freestanding Compact Coolers						
Avg. Installed Price (2020$)	526.92	534.73	590.50	686.10	789.22	819.75
Freestanding Coolers						
Avg. Installed Price (2020$)	1,754.97	1,775.85	1,850.65	1,942.14	2,257.79	2,371.94

Table 10.4.2 Combination Cooler Refrigeration Products: Total Installed Costs for No-New-Standards and Standards Cases

	No New Standards Case	Standard at Efficiency Level:				
		1	2	3	4	5
C-3A *(not directly analyzed)*						
Avg. Installed Price (2020$)	4,508.14	4,542.66	4,546.40	4,624.53	4,863.91	4,863.91
C-9 *(not directly analyzed)*						
Avg. Installed Price (2020$)	4,795.98	4,795.98	4,803.09	4,885.99	5,138.17	5,138.17
C-13A						
Avg. Installed Price (2020$)	1,872.30	1,875.67	1,879.64	2,010.78	2,115.09	2,115.08

As discussed in chapter 8 of this TSD, the historical price data specific to MREF are not available. Hence, for this preliminary analysis, DOE used a constant price assumption as the default product price trend to project the prices of MREF sold in each year in the analysis period. For each type of MREF, DOE also applied the same constant price trend to project prices for each product class at each considered EL.

The total annual increase in installed cost for a given standards case is the product of the total installed cost increase per unit due to the standard and the number of units of each vintage. This approach accounts for differences in total installed cost from year to year.

10.4.3 Annual Operating Costs Savings

Per-unit annual operating costs encompass the annual costs for energy, repair, and maintenance. DOE determined the savings in per-unit annual energy cost by multiplying the savings in per-unit annual energy consumption by the appropriate energy price, and any associated costs or savings for repair and maintenance.

As described in chapter 8 of this TSD, to estimate energy prices in future years, DOE multiplied the recent electricity prices by a projection of annual national-average residential electricity prices.

The total savings in annual operating costs for an EL is the product of the annual operating cost savings per unit under that standard and the number of units of each vintage. This approach accounts for differences in savings in annual operating costs from year to year.

10.4.4 Discount Factor

DOE multiplies monetary values in future years by a discount factor to determine present values. The discount factor (DF) is described by the equation:

$$DF = \frac{1}{(1+r)^{(y-y_p)}}$$

Where:

r = discount rate,
y = year of the monetary value, and
y_P = year in which the present value is being determined.

DOE uses both a 3-percent and a 7-percent real discount rate when estimating national impacts. Those discount rates were applied in accordance with the Office of Management and Budget (OMB)'s guidance to Federal agencies on developing regulatory analyses (OMB Circular A-4, September 17, 2003, and section E., "Identifying and Measuring Benefits and Costs," therein). DOE defined the present year as 2020.

10.4.5 Present Value of Increased Installed Costs and Savings

The present value of increased installed costs is the annual increase in installed cost for each year (*i.e.*, the difference between the standards case and no-new-standards), discounted to the present and summed over the forecast period (2029–2058). The increase in total installed cost refers to both product and installation costs associated with the higher energy efficiency of products purchased under a standards case compared to the no-new-standards case.[d] DOE calculated annual increases in installed cost as the difference in total cost of new products installed each year, multiplied by the shipments in the standards case.

The present value of operating cost savings is the annual savings in operating cost (the difference between the no-new-standards case and a standards case), discounted to the present and summed over the period that begins with the expected compliance date of potential standards and ends when the last installed unit is retired from service. Savings represent decreases in operating costs associated with the higher energy efficiency of products purchased in a standards case compared to the no-new-standards case. Total annual operating cost savings are the savings per unit multiplied by the number of units of each vintage that survive in a particular year. Because a product consumes energy throughout its lifetime, the energy consumption for units installed in a given year includes energy consumed until the unit is retired from service.

10.5 RESULTS

10.5.1 National Energy Savings

This section provides NES results that DOE calculated for each TSL analyzed for MREFs. NES results are shown as savings in both primary and FFC energy. Because DOE based the inputs to the NIA model on weighted-average values, results are discrete point values, rather than a distribution of values as produced by the life-cycle cost and payback period analysis.

[d] For the NIA, DOE excludes sales tax from the product cost, because sales tax is essentially a transfer and therefore is more appropriate to include when estimating consumer benefits.

Table 10.5.1 MREFs Cumulative National Primary Energy Savings Results in Quads

TSL	Compact Coolers (freestanding and built-in)	Coolers (freestanding and built-in)	Combination Coolers	Total*
1	0.13	0.00	0.00	0.13
2	0.21	0.01	0.00	0.22
3	0.35	0.01	0.01	0.37
4	0.39	0.02	0.01	0.42
5	0.40	0.02	0.01	0.43

*Total may not match sum due to rounding

Table 10.5.2 MREFs Cumulative National Energy Savings Full-Fuel-Cycle Results in Quads

TSL	Compact Coolers (freestanding and built-in)	Coolers (freestanding and built-in)	Combination Coolers	Total*
1	0.13	0.00	0.00	0.14
2	0.21	0.01	0.00	0.23
3	0.36	0.01	0.01	0.39
4	0.41	0.02	0.01	0.43
5	0.42	0.02	0.01	0.45

*Total may not match sum due to rounding

10.5.2 Net Present Value

This section provides results of calculating the NPV of consumer benefits for each TSL considered for MREFs. Results, which are cumulative, are shown as the discounted value of the net savings in dollar terms. DOE based the inputs to the NIA model on weighted-average values, yielding results that are discrete point values, rather than a distribution of values as in the LCC and payback period analysis.

Table 10.5.3 and Table 10.5.4 shows the results of calculating the NPV for each TSL analyzed for MREFs, at both a 3-percent and a 7-percent discount rate.

Table 10.5.3 Cumulative Net Present Value of Consumer Benefits for MREFs, 3-Percent Discount Rate

TSL	Compact Coolers (freestanding and built-in)	Coolers (freestanding and built-in)	Combination Coolers	Total*
	Million 2020 dollars			
1	787.1	8.3	11.9	807.4
2	(28.9)	(7.8)	24.9	(11.9)
3	(1,544.1)	(34.5)	(53.5)	(1,632.0)
4	(4,130.7)	(281.7)	(120.8)	(4,533.1)
5	(4,902.1)	(360.1)	(120.8)	(5,383.0)

Parentheses indicate negative (-) values.
*Total may not match sum due to rounding

Table 10.5.4 Cumulative Net Present Value of Consumer Benefits for MREFs, 7-Percent Discount Rate

TSL	Compact Coolers (freestanding and built-in)	Coolers (freestanding and built-in)	Combination Coolers	Total*
	Million 2020 dollars			
1	296.7	1.7	4.6	303.0
2	(143.1)	(10.4)	9.4	(144.1)
3	(956.7)	(28.6)	(28.9)	(1,014.2)
4	(2,216.8)	(149.5)	(61.6)	(2,427.9)
5	(2,592.1)	(189.3)	(61.6)	(2,843.0)

Parentheses indicate negative (-) values.
*Total may not match sum due to rounding

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CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

11.1 OVERVIEW

The consumer subgroup analysis evaluates potential impacts from new standards on any identifiable groups of consumers who may be disproportionately affected by a national energy conservation standard. When appropriate, DOE will conduct this analysis as one of the analyses for the notice of proposed rulemaking ("NOPR") should DOE determine to issue a NOPR. DOE will accomplish this, in part, by analyzing the life-cycle costs ("LCCs") and payback periods ("PBPs") for the identified consumer subgroups. DOE will evaluate variations in regional energy prices, energy use, and installation and operational costs that might affect the impacts of a standard to consumer subgroups. To the extent possible, DOE will obtain estimates of each input parameter's variability and will consider this variability in its calculation of consumer impacts.

DOE will determine the impact on consumer subgroups using the LCC Spreadsheet Model. The standard LCC analysis (described in chapter 8) focuses on the consumers that use miscellaneous refrigeration products ("MREFs"). DOE can use the LCC Spreadsheet Model to analyze the LCC for any subgroup by sampling only that subgroup. (Chapter 8 explains in detail the inputs to the model used in determining LCC and PBPs.)

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12.1 INTRODUCTION

The purpose of the manufacturer impact analysis ("MIA") is to identify and quantify the impacts of any potential new and/or amended energy conservation standards on manufacturers. The Process Rule[1] provides guidance for conducting this analysis with input from manufacturers and other interested parties. The U.S. Department of Energy ("DOE") will apply this methodology to its evaluation of any energy conservation standards for miscellaneous refrigeration products ("MREFs"). DOE will consider a wide range of quantitative and qualitative industry impacts. For example, a particular standard level could require changes to manufacturing practices, production equipment, raw materials, *etc*. DOE will identify and analyze these manufacturer impacts during the notice of proposed rulemaking ("NOPR") stage of the analysis.

DOE announced changes to the MIA format through a report issued to Congress in January 2006 entitled "Energy Conservation Standards Activities." (as required by section 141 of the Energy Policy Act of 2005 ("EPACT 2005"))[2] Previously, DOE did not report any MIA results before the NOPR phase; however, under this new format, DOE collects, evaluates, and reports preliminary information and data.

12.2 METHODOLOGY

DOE conducts the MIA in three phases, and further tailors the analytical framework based on the comments it receives. In Phase I, DOE creates an industry profile to characterize the industry and identify important issues that require consideration. In Phase II, DOE prepares an industry cash-flow model and considers what information it might gather in manufacturer interviews. In Phase III, DOE interviews manufacturers and assesses the impacts of standards both quantitatively and qualitatively. DOE assesses industry and subgroup cash flows and industry net present value ("INPV") using the Government Regulatory Impact Model ("GRIM"). DOE then assesses impacts on competition, manufacturing capacity, direct employment, and cumulative regulatory burden ("CRB").

12.2.1 Phase I: Industry Profile

In Phase I of the MIA, DOE collects pertinent qualitative and quantitative information about the market and manufacturer financials. This includes research and development ("R&D")

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[1] On December 13, 2021 the Department of Energy published a Process Rule clarifying the procedures used to evaluate the economic justification of new or amended energy conservation standards. 86 FR 70892

[2] This report is available on the DOE website at www1.eere.energy.gov/buildings/appliance_standards/pdfs/congressional_report_013106.pdf

expenses; selling, general, and administrative ("SG&A") expenses; capital expenditures; property, plant, and equipment ("PPE") expenses; tax rate; and depreciation rates for MREF manufacturers. Sources of information include reports published by industry groups, trade journals, annual company reports, and Securities Exchange Commission ("SEC") 10-K and 20-F filings, and prior DOE MREF and consumer refrigerator, refrigerator-freezer, and freezer rulemaking documents. The initial estimates of financial parameters are presented in section 12.3.1.

In addition, DOE develops a comprehensive manufacturer list, develops market share estimates, and evaluates consolidation trends, as presented in preliminary market and technology assessment (chapter 3 of the Technical Support Document ("TSD")). Characterizations of the current product offerings and market efficiency distributions are presented in the preliminary engineering analysis (chapter 5 of the TSD) and shipment analysis (chapter 9 of the TSD).

12.2.2 Phase II: Industry Cash Flow Analysis and Interview Guide

Phase II activities occur after publication of the preliminary analysis notice. In Phase II, DOE performs a preliminary industry cash-flow analysis and prepares an interview guide for manufacturer interviews.

12.2.2.1 Industry Cash Flow Analysis

DOE uses the GRIM to analyze the financial impacts of potential new and/or amended energy conservation standards. The implementation of these standards may require manufacturer investments (*i.e.*, conversion costs), raise manufacturer production costs ("MPCs"), and/or affect revenue possibly through higher prices and lower shipments. The GRIM uses a suite factors to determine annual cash flows for the years leading up to the compliance date of new and/or amended energy conservation standards and for 30 years after the compliance date. These factors include industry financial parameters, manufacturer production costs, conversion costs, shipment forecasts, and price forecasts. DOE compares the GRIM results for potential standard levels against the results for the no-new-standards case, in which energy conservation standards are not amended. The financial impact of analyzed amended energy conservation standards is the difference between the two sets of discounted annual cash flows.

12.2.2.2 Interview Guide

DOE conducts interviews with manufacturers to gather information on the effects new and/or amended energy conservation standards could have on revenues and finances, direct employment, capital assets, and industry competitiveness. These interviews take place during Phase III of the MIA. Before the interviews, DOE distributes an interview guide that will help identify the impacts of potential standard levels on individual manufacturers or subgroups of manufacturers within the MREF industry. The interview guide covers financial parameters, MPCs, market share, product mix, conversion costs, manufacturer markups and profitability, assessment of the impact on competition, manufacturing capacity, and other relevant topics.

12.2.3 Phase III: Industry and Subgroup Analysis

Phase III activities occur after publication of the preliminary analysis notice. These activities include manufacturer interviews; revision of the industry cash flow analysis; manufacturer subgroup analyses, where appropriate; an assessment of the impacts on industry competition, manufacturing capacity, direct employment, and the cumulative regulatory burden; and other qualitative impacts.

12.2.3.1 Manufacturer Interviews

DOE supplements the information gathered in Phase I and the cash-flow analysis constructed in Phase II with information gathered through interviews with manufacturers and written comments from stakeholders during Phase III.

DOE conducts detailed interviews with manufacturers to gain insight into the potential impacts of any new and/or amended energy conservation standards on sales, direct employment, capital assets, and industry competitiveness. Generally, interviews are scheduled well in advance to provide every opportunity for key individuals to be available for comment. Although a written response to the questionnaire is acceptable, DOE prefers interactive interviews, if possible, which help clarify responses and provide the opportunity to identify additional issues.

A non-disclosure agreement allows DOE to consider confidential or sensitive information in the decision-making process. Confidential information, however, is not made available in the public record. At most, sensitive or confidential information may be aggregated and presented in the form of industry-wide representations.

12.2.3.2 Revised Industry Cash Flow Analysis

During interviews, DOE requests information about profitability impacts, necessary plant changes, and other manufacturing impacts. Following any such interviews, DOE revises the preliminary cash-flow prepared in Phase II based on the feedback it receives during interviews.

12.2.3.3 Manufacturer Subgroup Analysis

The use of average cost assumptions to develop an industry cash flow estimate may not adequately assess differential impacts of potential amended energy conservation standards among manufacturer subgroups. Smaller manufacturers, niche players, and manufacturers exhibiting a cost structure that differs largely from the industry average could be more negatively or positively affected. DOE customarily uses the results of the industry characterization to group manufacturers with similar characteristics. When possible, DOE discusses the potential subgroups that have been identified for the analysis in manufacturer interviews. DOE asks manufacturers and other interested parties to suggest what subgroups or characteristics are most appropriate for the analysis. One subgroup commonly identified is small business manufacturers.

12.2.3.4 Competitive Impact Assessment

EPCA directs DOE to consider the impact of any lessening of competition, as determined in writing by the Attorney General, that is likely to result from a proposed standard. (42 U.S.C. 6295(o)(2)(B)(i)(V)) It also directs the Attorney General to determine the impact, if any, of any lessening of competition likely to result from a proposed standard and to transmit such determination to the Secretary within 60 days of the publication of a proposed rule, together with an analysis of the nature and extent of the impact. (42 U.S.C. 6295(o)(2)(B)(ii)) Furthermore, as part of the MIA, DOE evaluates the potential impact of standards to create asymmetric cost increases for manufacturer sub-groups, shifts in competition due to proprietary technologies, and business risks due to limited supplier availability or raw material constraints.

12.2.3.5 Manufacturing Capacity Impact

One of the potential outcomes of new and/or amended energy conservation standards is the obsolescence of existing manufacturing assets, including tooling and other investments. The manufacturer interview guide has a series of questions to help identify impacts on manufacturing capacity, specifically capacity utilization and plant location decisions in North America with and without amended energy conservation standards; the ability of manufacturers to upgrade or remodel existing facilities to accommodate the new requirements; the nature and value of any stranded assets; and estimates for any one-time restructuring or other charges, where applicable.

12.2.3.6 Direct Employment Impacts

The impact of potential new and/or amended energy conservation standards on direct employment is considered in DOE's analysis. Manufacturer interviews aid in assessing how domestic employment patterns might be impacted by new and/or amended energy conservation standards. Typically, the interview guide contains a series of questions that are designed to explore current employment trends in the MREF industry and to solicit manufacturers' views on changes in direct employment patterns that may result from increased standard levels. These questions focus on current employment levels at production facilities, expected future direct employment levels with and without changes in energy conservation standards, differences in workforce skills, and employee retraining.

12.2.3.7 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects on manufacturers of potential new and/or amended energy conservation standards and other Federal regulatory actions affecting the same products or companies within a short timeframe. DOE analyzes and considers the impact of multiple, product-specific, Federal regulatory actions on manufacturers.

12.3 PRELIMINARY FINDINGS

The following section summarizes information gathered for the preliminary MIA that are not already presented in the market and technology assessment ("MTA"), engineering analysis, or shipments analysis.

12.3.1 Initial Financial Parameters

DOE chose to begin the analysis of industry financial parameters with values presented in the October 2016 Direct Final Rule. 81 FR 75194. The October 2016 Direct Final Rule financial parameters were vetted by multiple manufacturers in confidential interviews and went through public notice and comment. The results are the most robust product-specific estimates that are publicly available for MREFs.

DOE compared those values with the current financial parameters of six public companies engaged in manufacturing and selling MREFs to confirm that the parameters were still relevant. DOE noted that tax rate estimates from before 2018 were not relevant for modeling future cash-flows due to the Tax Cuts and Jobs Act ("TCJA"), which was signed into law in December 2017 and changed the Federal corporate tax rate from 35 percent to 21 percent.[3] Table 12.3.1 below shows DOE's initial financial parameter estimates, which align with the prior MREF rulemaking. DOE will further refine these values using feedback from manufacturer and public comments.

[3] The Tax Cuts and Jobs Act of 2017 made changes to the taxation of corporate taxpayers, including replacing the graduated corporate tax structure with a flat 21 percent corporate tax rate. Additional information is available at www.irs.gov/newsroom/after-tax-reform-many-corporations-will-pay-blended-tax-rate (published November 7, 2018)

Table 12.3.1 Financial Parameters Based on the October 2016 Direct Final Rule

Financial Metric	Estimate
Tax Rate ***(% of Taxable Income)***	23.4*
Working Capital ***(% of Revenue)***	5.8
SG&A ***(% of Revenue)***	13.2
R&D ***(% of Revenues)***	1.6
Depreciation ***(% of Revenues)***	3.9
Capital Expenditures ***(% of Revenues)***	3.9
Net Property, Plant, and Equipment ***(% of Revenues)***	14.3

*Adjusted from the October 2016 Direct Final Rule value to reflect the change in the Federal corporate tax rate due to the TCJA.

The manufacturer selling price ("MSP") is the price manufacturers charge their first customers. The MSP equals the MPC multiplied by the manufacturer markup. The manufacturer markup covers all manufacturer non-production costs (*e.g.,* SG&A, R&D, and interest) and profit. The MSP is different from the cost the end-user pays because there are additional markups from entities along the distribution chain between the manufacturer and the end-user.

DOE considered the average manufacturer markup from the October 2016 Direct Final Rule to be the most robust product-specific data available. DOE estimated the industry average manufacturer markup to be 1.25 for the freestanding compact cooler product class and 1.41 for all other MREF product classes.

12.3.2 Manufacturers and Manufacturer Subgroups

DOE reviewed its Compliance Certification Management System ("CCMS"),[4] California Energy Commission's Modernized Appliance Efficiency Database System ("MAEDbS"),[5] retailer websites, and the prior MREF energy conservation standards rulemaking to identify manufacturers of the covered product. DOE identified 72 companies that import, private label, produce, or manufacture MREFs. DOE notes that it can be difficult to differentiate between companies that import, private label, produce, and manufacture based on public information. Many companies offer a mix of imported, private labeled, and in-house manufactured product. Using available information from manufacturer websites, manufacturer specifications and

[4] Accessible at www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A*.

[5] California Energy Commission's MAEDbS is available at cacertappliances.energy.ca.gov/Pages/ApplianceSearch.aspx (last accessed October 6, 2021).

product literature, import and export data, site images, and basic model numbers, DOE estimates 26 of these companies are original equipment manufacturers ("OEMs") of covered products.

DOE performed a preliminary investigation into small business manufacturers as a subgroup for consideration in subsequent stages of the MREF rulemaking. DOE relied on the Small Business Association ("SBA") size standards for determining the threshold for a firm to be a "small business." The SBA size standards are set based on the North American Industry Classification System ("NAICS") code. The manufacturers of the products covered in this rulemaking have a primary NAICS code of 335220: "Major Household Appliance Manufacturing" or 333415: "Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing. The SBA defines a small business as a company that has fewer than 1,500 employees and fewer than 1,250 employees for NAICS codes 335220 and 333415, respectively. The size threshold is based on enterprise-wide employment, which includes enterprise subsidiaries and branches, as well as unrelated establishments of the parent company. DOE used the higher threshold of 1,500 employees to identify small business manufacturers.

DOE identified 42 small companies that import, private label, produce, or manufacture MREFs. As noted earlier in this section, there is limited information to enable DOE to differentiate between companies that import, private label, produce, and manufacture. DOE estimates 14 of the small businesses are OEMs of covered products. Of the 14 small OEMs, approximately two are headquartered in the United States and would meet the SBA definition of a "small business." DOE will continue its investigation of small business manufacturers in future phases of the MIA through manufacturer interviews and the notice and comment process.

12.3.3 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several impending regulations may have significant consequences for individual manufacturers, groups of manufacturers, or entire industries. In the cumulative regulatory burden ("CRB") analysis, DOE considers expenditures associated with meeting other Federal, product-specific regulations that occur within the CRB timeframe. DOE will use the seven-year period that covers with three years before the compliance year, the compliance year, and the three years after the compliance year of the proposed standard, as the CRB timeframe.

In the MIA's Phase III (as described in section 12.2.3 of this TSD), which is conducted after the publication of the preliminary analysis, manufacturer interviews help DOE identify potential opportunities to coordinate regulatory actions in a manner that mitigates cumulative impacts, such as multiple successive redesigns of the same product with a short period of time. Many of the MREF manufacturers produce other home appliances and products that are regulated by DOE efficiency standards. MREF manufacturers are subject to efficiency standard for products such as Cooking Products, Dishwashers, Central Air Conditioners, Furnaces, and Refrigerators, refrigerator-freezers, and freezers. The exact regulations contributing to CRB will be determined once a compliance date is proposed in the NOPR phase.

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13.1 OVERVIEW

The U.S. Department of Energy (DOE) conducts an emissions analysis for the notice of proposed rulemaking (NOPR) stage should DOE determine to issue a NOPR. In the emissions analysis, DOE estimates the reduction in power sector combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), mercury (Hg), methane (CH_4) and nitrous oxide (N_2O) from potential energy conservation standards for the considered products, as well as emissions at the building site if applicable. In addition, DOE estimates emissions impacts in production activities (extracting, processing, and transporting fuels) that provide the energy inputs to power plants and for site combustion. These are referred to as "upstream" emissions. Together, these emissions account for the full-fuel-cycle (FFC). In accordance with DOE's FFC Statement of Policy (76 FR 51282 (August 18, 2011)), the FFC analysis includes impacts on emissions of methane and nitrous oxide, both of which are recognized as greenhouse gases.

DOE conducts the emissions analysis using marginal emissions factors that are primarily derived from data in the latest version of the Energy Information Administration's (EIA's) *Annual Energy Outlook* (*AEO)*, supplemented by data from other sources. EIA prepares the *AEO* using the National Energy Modeling System (NEMS).[a] Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions.

Site emissions of CO_2 and NO_X are estimated using emissions intensity factors from a publication of the Environmental Protection Agency (EPA).[1] Combustion emissions of CH_4 and N_2O are estimated using emissions intensity factors published by the EPA GHG Emissions Factors Hub.[b] The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).[2] The upstream emissions include both emissions from fuel combustion during extraction, processing and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

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[a] For more information about NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is National Energy Modeling System: An Overview 2009, DOE/EIA-0581 (October 2009), available at: https://www.eia.gov/outlooks/aeo/nems/overview/pdf/0581(2009).pdf
[b] https://www.epa.gov/sites/production/files/2016-09/documents/emission-factors_nov_2015_v2.pdf

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2. Coughlin, K. *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*. 2013. Lawrence Berkeley National Laboratory: Berkeley, CA. Report No. LBNL-6025E. (Last accessed March 31, 2021.) https://eta-publications.lbl.gov/sites/default/files/lbnl6025e_ffc.pdf.

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CHAPTER 14. MONETIZATION OF EMISSIONS REDUCTIONS BENEFITS

14.1 OVERVIEW

The U.S. Department of Energy ("DOE") estimates the monetary benefits associated with the reduced emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur dioxide (SO_2), and nitrogen oxides (NO_X) that are expected to result from the considered standard levels in the notice of proposed rulemaking ("NOPR") stage, should DOE determine to issue a NOPR. To make this calculation similar to the calculation of the net present value of consumer benefit, DOE considers the reduced emissions expected to result over the lifetime of products shipped in the projection period for each standard level.

DOE estimates the monetized benefits of the reductions in emissions of CO_2, CH_4, and N_2O by using a measure of the social cost ("SC") of each pollutant. These estimates represent the monetary value of the net harm to society associated with a marginal increase in emissions of these pollutants in a given year, or the benefit of avoiding that increase. These estimates are intended to include (but are not limited to) climate-change-related changes in net agricultural productivity, human health, property damages from increased flood risk, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services.

DOE uses the estimates for the social cost of greenhouse gases ("SC-GHG") from the most recent update of the Interagency Working Group on Social Cost of Greenhouse Gases, United States Government ("IWG") working group, from "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990." (February 2021 TSD).[a] DOE has determined that the estimates from the February 2021 TSD, as described more below, are based upon sound analysis and provide well founded estimates for DOE's analysis of the impacts of related to the reductions of emissions anticipated from the proposed rule.

The SC-GHG estimates in the February 2021 TSD are interim values developed under Executive Order (E.O.) 13990 for use until an improved estimate of the impacts of climate change can be developed based on the best available science and economics. The SC-GHG estimates used in this analysis were developed over many years, using a transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. Specifically, an IWG that included DOE, the EPA and other executive branch agencies and offices used three integrated assessment models ("IAMs") to develop the SC-CO_2 estimates and recommended four global values for use in regulatory analyses. Those estimates were subject to public comment in the context of dozens of proposed rulemakings as well as in a dedicated public comment period in 2013.

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[a] See Interagency Working Group on Social Cost of Greenhouse Gases, Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide. Interim Estimates Under Executive Order 13990, Washington, D.C., February 2021.
https://www.whitehouse.gov/wpcontent/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf?source=email

The SC-CO_2 estimates were first released in February 2010 and updated in 2013 using new versions of each IAM. In 2015, as part of the response to public comments received to a 2013 solicitation for comments on the SC-CO_2 estimates, the IWG announced a National Academies of Sciences, Engineering, and Medicine review of the SC-CO_2 estimates to offer advice on how to approach future updates to ensure that the estimates continue to reflect the best available science and methodologies. In January 2017, the National Academies released their final report, Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide, and recommended specific criteria for future updates to the SC-CO_2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process (National Academies 2017). On January 20, 2021, President Biden issued Executive Order 13990, which directed the IWG to ensure that the U.S. Government's ("USG") estimates of the SC-CO_2 social cost of carbon and other greenhouse gases reflect the best available science and the recommendations of the National Academies (2017). The IWG was tasked with first reviewing the estimates currently used by the USG and publishing interim estimates within 30 days of E.O. 13990 that reflect the full impact of GHG emissions, including taking global damages into account, which resulted in the issuance of the February 2021 TSD. More information on the basis for the IWG's interim values may be found in the IWG's Technical Support Document.

To estimate the monetary value of reduced NO_X and SO_2 emissions from electricity generation attributable to the standard levels it considers, DOE uses benefit-per-ton estimates derived from analysis conducted by the EPA. For NO_X and SO_2 emissions from combustion at the site of product use, DOE uses another set of benefit-per-ton estimates published by the EPA.

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15.1 OVERVIEW

The U.S. Department of Energy ("DOE") analyzes the changes in electric installed capacity and power generation that result for each considered trial standard level for the notice of proposed rulemaking ("NOPR") stage should DOE determine to issue a NOPR.

The utility impact analysis is based on output of the DOE/Energy Information Administration ("EIA")'s National Energy Modeling System ("NEMS").[1] NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the Annual Energy Outlook ("AEO"). The EIA publishes a reference case, which incorporates all existing energy-related policies at the time of publication, and a variety of side cases which analyze the impact of different policies, energy price and market trends.

DOE's methodology is based on results published for the most recent AEO Reference case, as well as a number of side cases that estimate the economy-wide impacts of changes to energy supply and demand. DOE estimates the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards. DOE uses the side cases to estimate the marginal impacts of reduced energy demand on the utility sector. These marginal factors are estimated based on the changes to electricity sector generation, installed capacity, fuel consumption and emissions in the AEO Reference case and various side cases. The methodology is described in more detail in K. Coughlin, "Utility Sector Impacts of Reduced Electricity Demand."[2,3]

The output of this analysis is a set of time-dependent coefficients that capture the change in electricity generation, primary fuel consumption, installed capacity and power sector emissions due to a unit reduction in demand for a given end use. These coefficients are multiplied by the stream of electricity savings calculated in the NIA to provide estimates of selected utility impacts of new or amended energy conservation standards.

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16.1 OVERVIEW

Energy conservation standards can impact employment both directly and indirectly. Direct employment impacts are changes in the number of employees at the plants that produce the covered miscellaneous refrigeration products ("MREFs") resulting from standards, and are evaluated in the manufacturer impact analysis, as described in chapter 12 of this Technical Support Document. The employment impact analysis described in this chapter covers indirect employment impacts which may result from expenditures shifting between goods (the substitution effect) and changes in income and overall expenditure levels (the income effect) that occur due to the implementation of standards. The U.S. Department of Energy ("DOE") conducts this analysis in the notice of proposed rulemaking ("NOPR") stage should DOE determine to issue a NOPR.

DOE expects new or amended energy conservation standards to decrease energy consumption and, therefore, reduce expenditures for energy. In turn, savings in energy expenditures may be redirected for new investment and other items. Notwithstanding, energy conservation standards may potentially increase the purchase price of MREF, including the retail price plus sales tax, and may increase installation costs.

Using an input-output model of the U.S. economy, the employment impact analysis seeks to estimate the year-to-year effect of these expenditure impacts on net national employment. DOE intends the employment impact analysis to quantify the indirect employment impacts of these expenditure changes.

To investigate the indirect employment impacts, DOE uses the Pacific Northwest National Laboratory ("PNNL") "Impact of Sector Energy Technologies" (ImSET 3.1.1) model.[1] PNNL developed ImSET, a spreadsheet model of the U.S. economy that focuses on 187 sectors most relevant to industrial, commercial, and residential building energy use, for DOE's Office of Energy Efficiency and Renewable Energy. ImSET is a special-purpose version of the U.S. Benchmark National Input-Output ("I-O") model, which has been designed to estimate the national employment and income effects of energy saving technologies that are deployed by DOE's Office of Energy Efficiency and Renewable Energy. In comparison with the previous versions of the model used in earlier rulemakings, this version allows for more complete and automated analysis of the essential features of energy efficiency investments in buildings, industry, transportation, and the electric power sectors.

The ImSET software includes a computer-based I-O model with structural coefficients to characterize economic flows among the 187 sectors. ImSET's national economic I-O structure is based on the 2002 Benchmark U.S. table, specially aggregated to 187 sectors.[2]

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17.1 INTRODUCTION

Under appendix A to subpart C of Title 10 of the Code of Federal Regulations, Part 430, *Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products* (the "Process Rule") the U.S. Department of Energy ("DOE") is committed to explore non-regulatory alternatives to energy conservation standards. Accordingly, DOE will prepare a draft regulatory impact analysis pursuant to Executive Order 12866, "Regulatory Planning and Review," which will be subject to review by the Office of Management and Budget's Office of Information and Regulatory Affairs for the notice of proposed rulemaking ("NOPR"). Pursuant to the Process Rule, DOE has identified five major alternatives to standards that represent feasible policy options to reduce the energy consumption of miscellaneous refrigeration products ("MREFs"). It will evaluate each alternative in terms of its ability to achieve significant energy savings at a reasonable cost, and will compare the effectiveness of each alternative to the effectiveness of the proposed standard.

Table 17.1.1 lists the non-regulatory means of achieving energy savings that DOE proposes to analyze. The technical support document ("TSD") prepared in support of DOE's NOPR will include a complete quantitative analysis of each alternative, the methodology for which is briefly addressed below.

Table 17.1.1 Non-Regulatory Alternatives to Standards

No New Regulatory Action
Consumer Rebates
Consumer Tax Credits
Manufacturer Tax Credits
Voluntary Energy Efficiency Targets
Bulk Government Purchases

17.2 METHODOLOGY

DOE will use the national impact analysis ("NIA") spreadsheet model for MREF to calculate the national energy savings and the net present value ("NPV") corresponding to each candidate standard. The NIA model is discussed in chapter 10 of the TSD. To compare each alternative quantitatively to the proposed energy conservation standards, DOE will need to quantify the effect of each alternative on the purchase of energy efficient MREF. DOE will create an integrated NIA-RIA model, built upon the NIA model, where DOE will make the appropriate revisions to the inputs in the NIA models. Key inputs that DOE may revise in the NIA-RIA model are:

- MREF market shares of products meeting target efficiency levels (identical to the trial standard levels for the mandatory standards)

- Shipments of MREFs, when those are affected by the proposed energy conservation standards.

The following are the key measures of the impact of each alternative:

- *National energy savings*: Cumulative national energy use from the no-new-standards case projection minus the alternative-policy-case projection.
- *Net present value*: The value of future operating cost savings from the equipment bought during the period from the required compliance date of the new standard 2029 to 2058. DOE will calculate the NPV as the difference between the present value of equipment and operating expenditures (including energy) in the no-new-standards case, and the present value of expenditures under each alternative-policy case. DOE will calculate operating expenses (including energy costs) for the life of the equipment. It will discount future operating and equipment expenditures to 2021 using a 7-percent and 3-percent real discount rate.

APPENDIX 3A. CURRENT MARKET ENERGY EFFICIENCY BY PRODUCT CLASS

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APPENDIX 3A. CURRENT MARKET ENERGY EFFICIENCY BY PRODUCT CLASS

3A.1 INTRODUCTION

As discussed in chapter 3 of this technical support document ("TSD"), DOE analyzed and plotted the total adjusted volume ("TAV") and certified annual energy use ("AEU") for each product class based on DOE's Compliance Certification Management System ("CCMS") as of September 2021. On each plot DOE included curves representing the current maximum allowable energy consumption (*i.e.*, the current DOE energy conservation standard) and current ENERGY STAR ("ESTAR") standard level, if applicable. These plots provide a visual overview of the energy efficiencies available in each product class covered by this rulemaking.

3A.2 ENERGY EFFICIENCY BY PRODUCT CLASS

Based on the CCMS database, of the 12 product classes currently listed in DOE's standards for MREFs, 7 have certified models. Product classes C-9I and C-9-BI do not have any certified products as of September 2021. Additionally, the models currently certified under C-3A, C-13A-BI, and C-9I-BI appeared to not fully meet those product class definitions (but met the definitions of other refrigeration product classes). As such, models which appeared to be certified under the incorrect product class (*e.g.*, based on certified TAV outside of the specified range for a given product class) are not included within the plots of this appendix. See Chapter 3 for further details.

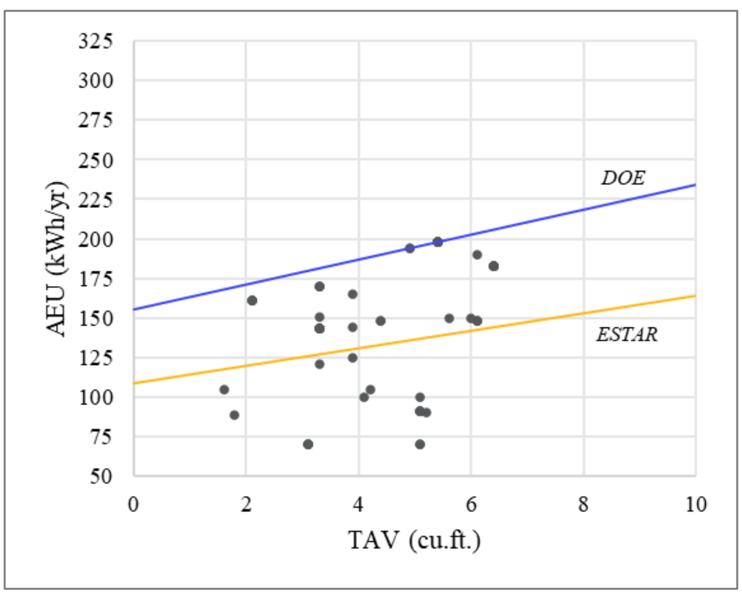

Figure 3A.1 Annual Energy Consumption for Built-In Compact Coolers

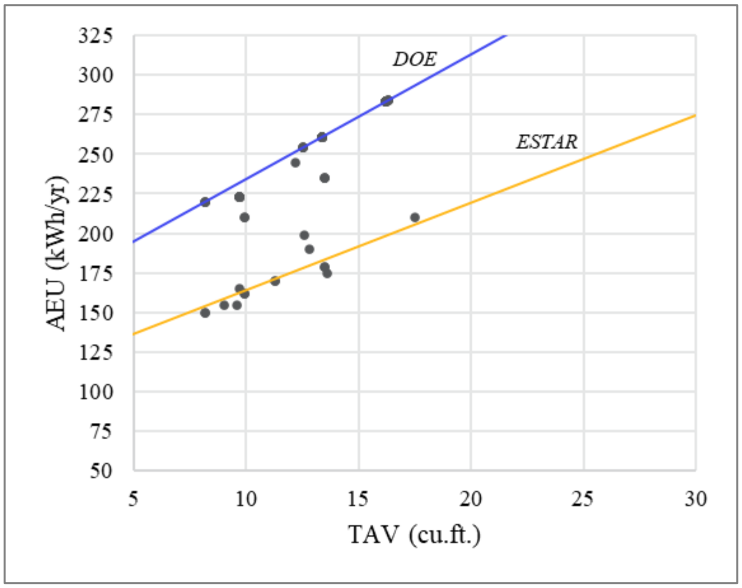

Figure 3A.2 Annual Energy Consumption for Built-In Coolers

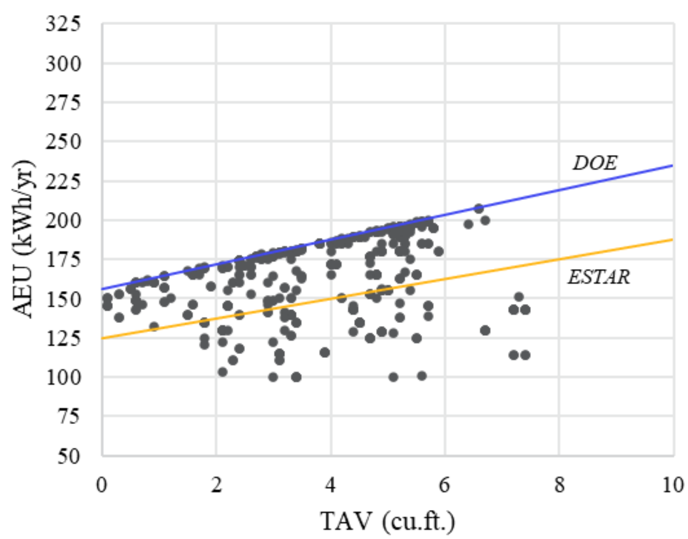

Figure 3A.3 Annual Energy Consumption for Freestanding Compact Coolers

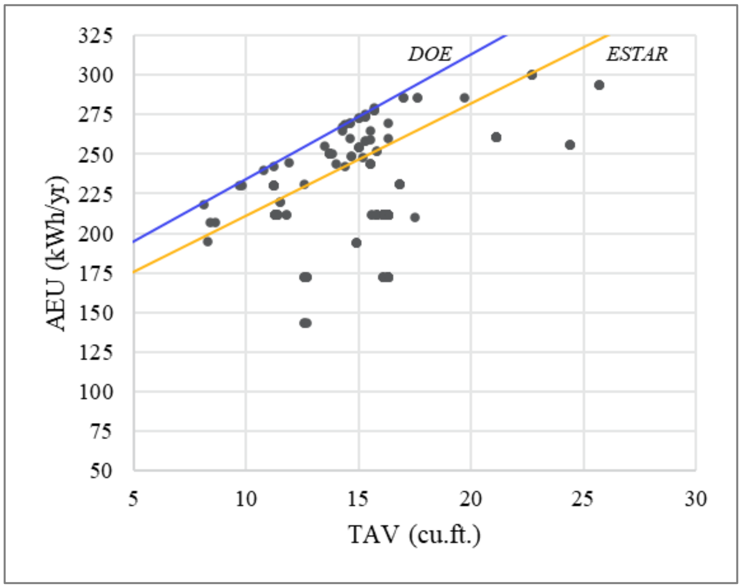

Figure 3A.4 Annual Energy Consumption for Freestanding Coolers

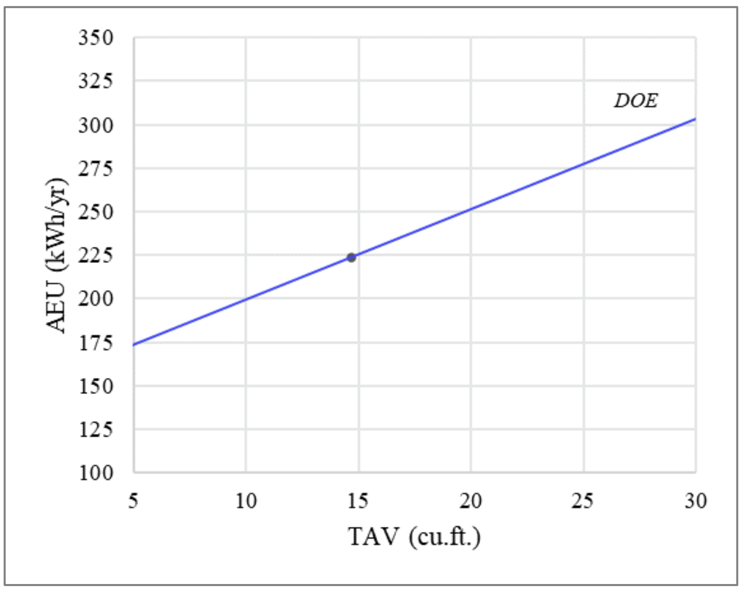

Figure 3A.5 Annual Energy Consumption for Product Class C-3A-BI

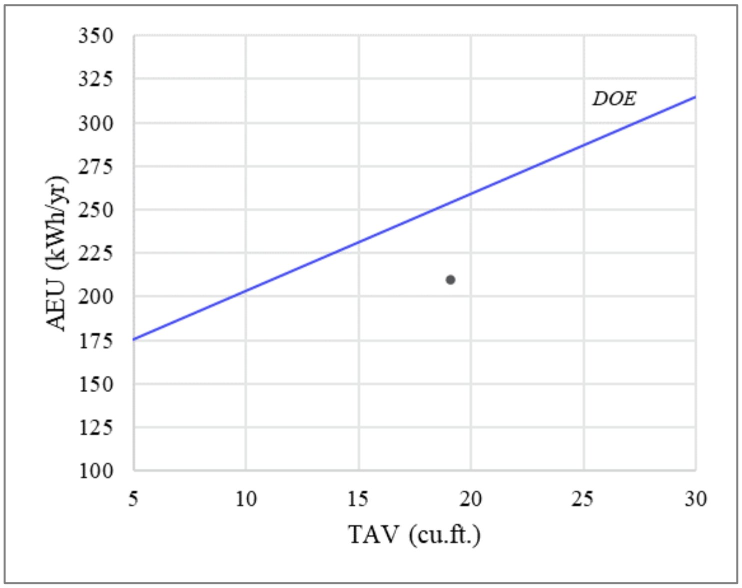

Figure 3A.6 Annual Energy Consumption for Product Class C-9

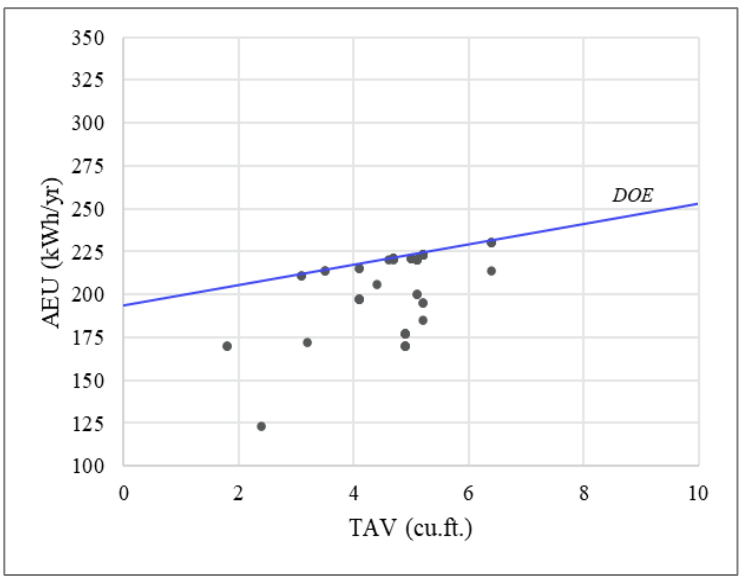

Figure 3A.7 Annual Energy Consumption for Product Class C-13A

APPENDIX 6A. INCREMENTAL MARKUPS: THEORY AND EVIDENCE

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APPENDIX 6A. INCREMENTAL MARKUPS: THEORY AND EVIDENCE

6A.1 INTRODUCTION

Since 2004, the Department of Energy ("DOE") has applied the incremental markup approach to estimate the increase in final product price of high-efficiency products as a function of the increase in manufacturing cost.[1] Under this approach, DOE applies a lower markup than the average markup to the incremental cost of higher-efficiency products, relative to the baseline product. The approach is described in detail in chapter 6.

DOE's incremental markup approach is based on the widely accepted economic view that prices closely reflect marginal costs in competitive markets and in those with some degree of concentration. Evaluating industry data in IBISWorld suggests that most of the industries relevant to appliance wholesalers and appliance retailers are considered to have low to moderate market concentration, high and increasing market competition and medium barriers to entry (see Table 6A.1.1 and Table 6A.1.2).[2,3]

Table 6A.1.1 Competitive Environment of Appliance Wholesalers

Sector	Industry Concentration	Competition	Barriers to Entry
TV & appliance wholesaling	Low	High and steady	Medium and steady
Refrigeration equipment wholesaling	Low	Medium and increasing	Medium and increasing
Heating & air-conditioning wholesaling	Low	High and steady	Medium and increasing

Table 6A.1.2 Competitive Environment of Appliance Retailers

Sector	Industry Concentration	Competition	Barriers to Entry
TV & appliance retailers	Low	High and steady	Medium and steady
Consumer electronics stores	Medium	High and Increasing	Medium and steady
Department stores	High	High and increasing	Medium and steady
Home improvement stores	High	Medium and steady	Medium and steady

* Note that there is competition between the four types of appliance retailers listed in this table, as well as within each individual retailing type.

Examining gross margin and price data in the appliance retail industry over time, DOE finds that both gross margins and prices did not demonstrate any persistent trend. Similarly, appliance wholesale gross margins and prices have both been effectively constant in past two decades. Thus, these sets of historical data have no bearing on firm markup behavior under product price increases, such as may occur as a result of standards.

To investigate markup behavior under product price increases, DOE evaluated time series gross margin data from three industries with rapidly changing input prices – the LCD television retail market, the U.S. oil and gasoline market, and the U.S. housing market. Additionally, LBNL conducted an in-depth interview with an HVAC consultant who represents many individual contractors in the industry.

6A.2 MARGIN TRENDS UNDER PRICE VOLATILITY

The market data on appliance wholesalers handling miscellaneous refrigeration products are not available at this point. Since the heating and air-conditioning wholesale industry has similar competition landscape as appliance wholesale industry (Table 6A.1.1), DOE turns to analyze the publicly available market data for heating and air-conditioning wholesaler and assumes that the results are generally applicable for appliance wholesalers as well. Heating, Air-Conditioning and Refrigeration Distributors International ("HARDI") published annual profit report with aggregated financial and operating data of its participating firms in HVAC wholesale industry. DOE evaluated the percent gross margins[a] and sales revenue per shipment received (as a proxy for average HVAC wholesale prices) reported from 1999 to 2012 for typical HARDI distributors.[b] As shown in Figure 6A.2.1, average HVAC wholesaler prices have experienced some fluctuations during this period of time, but the overall wholesale price trend is relatively stable, with a price increase of four percent from 1999 to 2012.

The U.S. Census Annual Retail Trade Survey (ARTS) provides gross margin data for electronics and appliance stores (NAICS 443) for 1993 to 2008. DOE calculated the shipments weighted average price of major household appliances (*i.e.*, refrigerators, freezers, clothes washers, dishwashers, and room air-conditioners) for the same time period from AHAM shipments and value of shipments data.[c] As seen in HVAC wholesaling, percent gross margins for appliance retailers and average appliance prices have been fairly stable (Figure 6A.2.2).

However, the existence of constant percent margin over time is not sufficient to identify an industry's markup practice without considering the underlying input price changes during the same period. If the prices have been relatively constant, the incremental markup approach will arrive at the same result as applying constant margin. In fact, the average prices have been relatively stable over time; [d] hence, the historically constant percent margins do not necessarily imply a constant percent margin in the future, especially in the case of increased input prices due to standards.

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[a] Percent gross margin is defined as gross margin in percentage of sales revenue.
[b] The typical distributors are the firms with median financial results among all participating firms.
[c] AHAM Annual Trends - Industry Shipments of Major Appliances; AHAM History of Dollar Value Report.
[d] In 2005 the HVAC market experienced a brief 15% price rise. The HVAC price increase may be attributed to the 2006 Central Air-Conditioner and Heat Pump Standard. Gross margins declined slightly at this time.

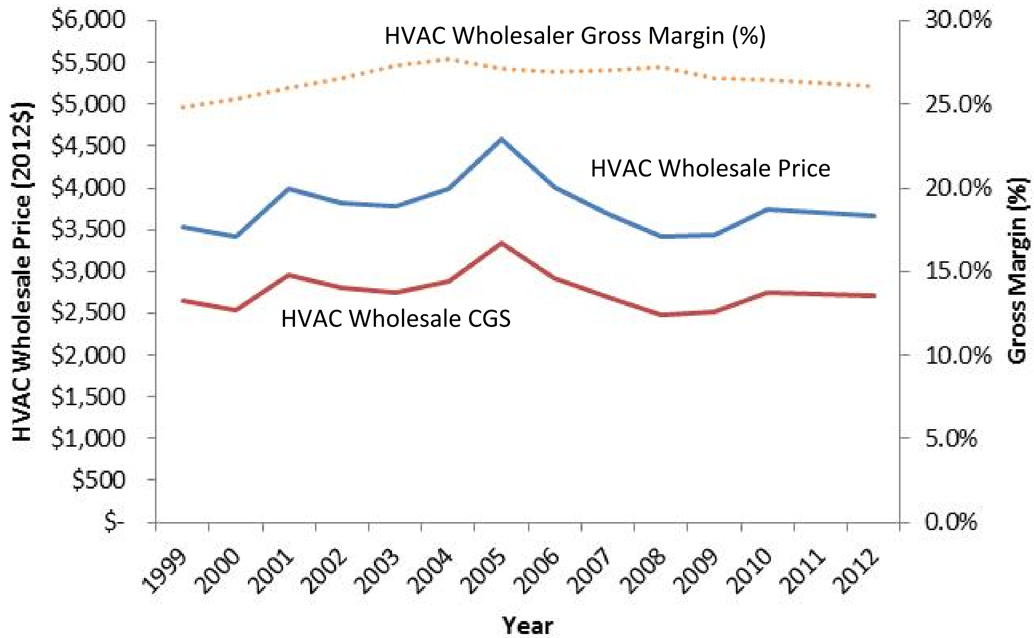

Figure 6A.2.1 HVAC Wholesale Prices, Cost of Goods Sold and Gross Margins

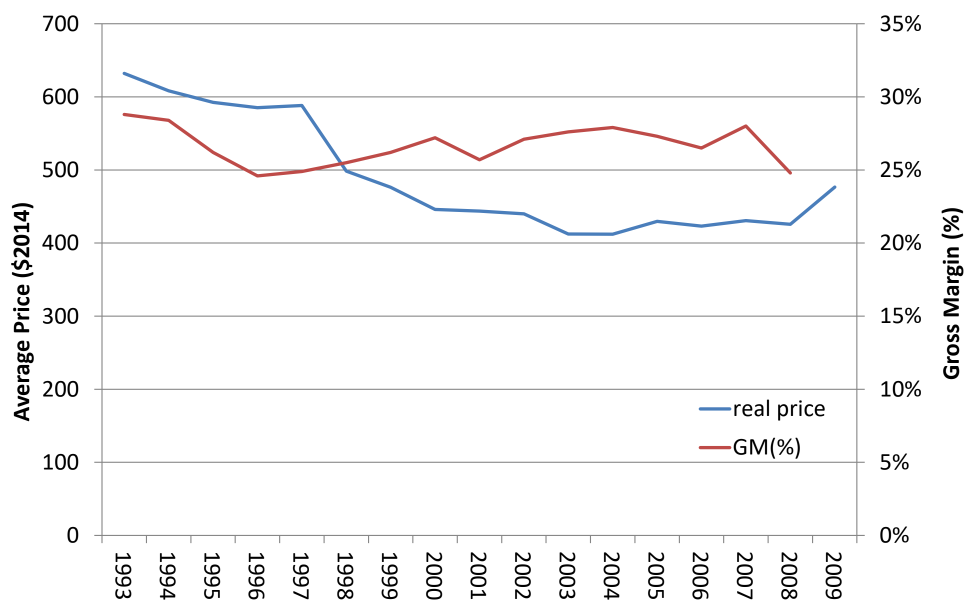

Figure 6A.2.2 Retail Appliance Prices and Gross Margins

As historical data in HVAC wholesale and appliance retail markets cannot be used to address the question of margins under a standards-induced price shock, DOE looks to other publicly available data for markets of products that have experienced noticeable price changes, evaluating the prevalence of fixed percent gross margins.

To replicate the theorized conditions of efficiency standard implementation, DOE would ideally analyze a household durable that has experienced a consistent rise in price, such as may occur as a result of standards. The LCD television retail market, on the other hand, is a market with a consistently downward price trend since 2007. The material costs and retail prices of LCD televisions have both dropped substantially over this period. At the same time, average retailer gross margins have decreased from 25 percent in 2007 to only 6 percent in late 2014. Under the input price change (CGS), retailers did not maintain constant percent gross margins (Figure 6A.2.3).[e]

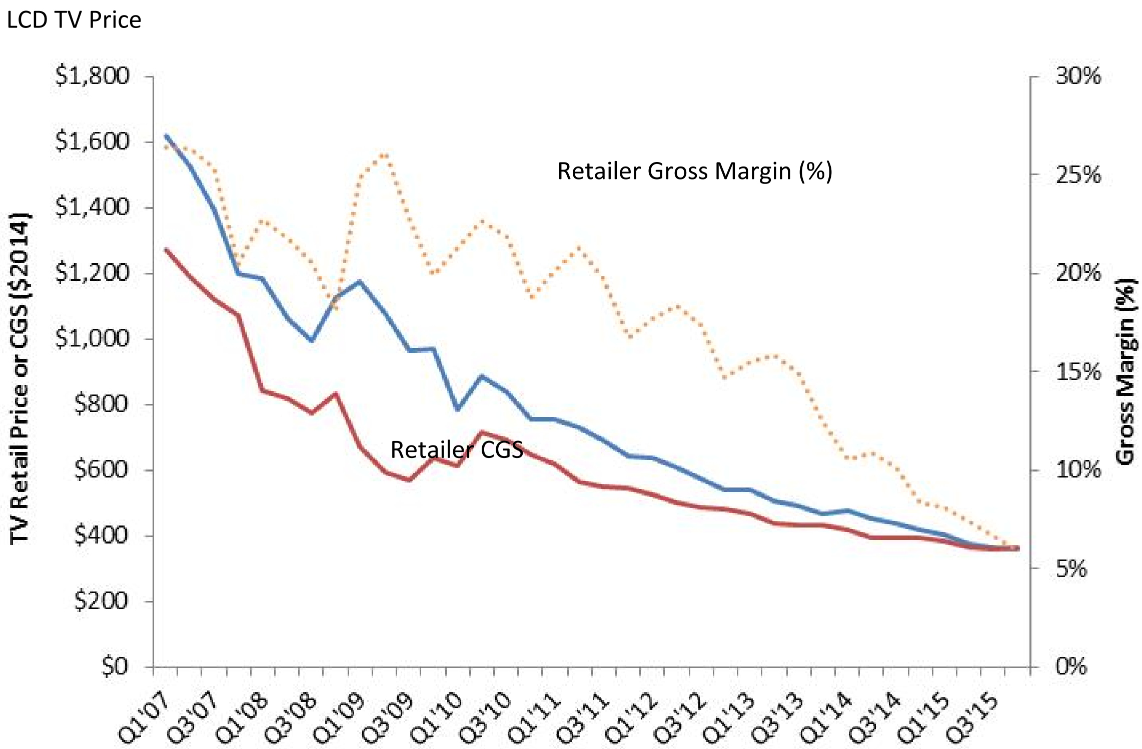

Figure 6A.2.3 LCD TV Prices, Cost of Goods Sold and Gross Margins

DOE also analyzed margin behavior in markets with upward price trends in order to test the prevalence of fixed percent gross margins. U.S. imported crude oil prices rose by $2.50 per gallon from 1995 to 2008, but the percent retail gross margins have decreased during the same period of time (Figure 6A.2.4).[4]

[e] LCD television data from DisplaySearch, a market research company affiliated with NPD Group.

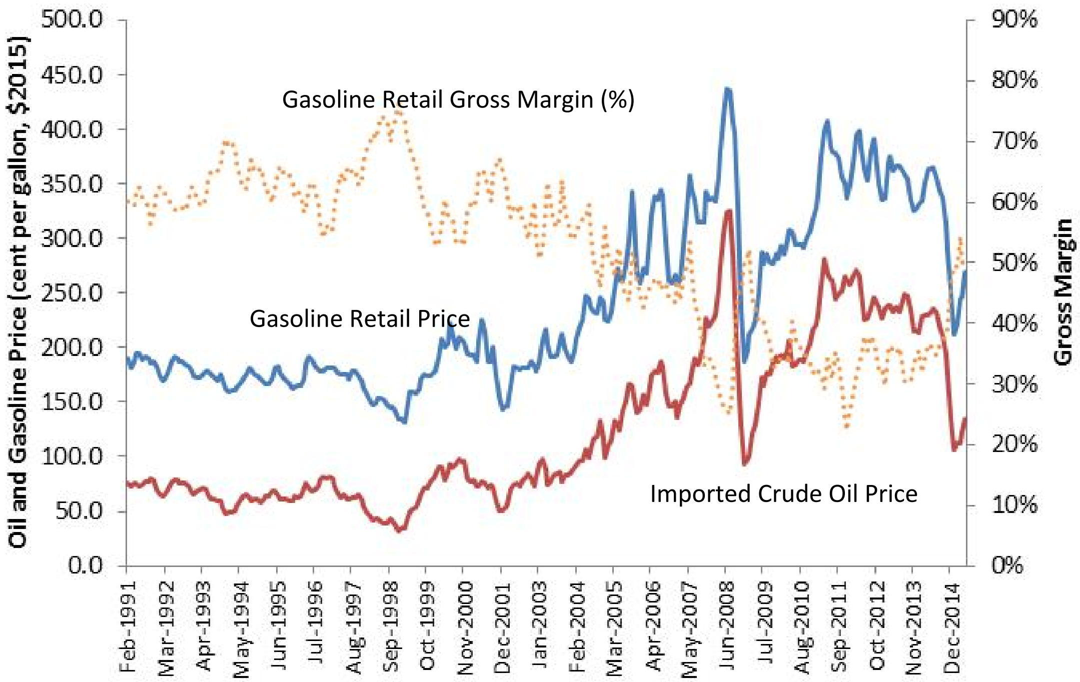

Figure 6A.2.4 Oil and Gasoline Price, Gross Margin

The U.S. inflation-adjusted median home sales prices and the costs of selling, measured by home sales price minus agent's commission fee, have increased substantially from 1991 to 2005. The percent gross margin in the housing market (*i.e.*, commission rate), however, has declined by 15 percent over this period (Figure 6A.2.5).[5,6,7,8f] In short, fixed percent gross margins in this market with increasing costs are not observed.

[f] Federal Trade Commission and the U.S. Department of Justice published a report, titled "Competition in the Real Estate Brokerage Industry", which provides extensive literature review on the topic of housing prices and brokerage commission fee, and the empirical evidences are consistent with our findings. Access to the full report: www.ftc.gov/reports/competition-real-estate-brokerage-industry-report-federal-trade-commission-us-department

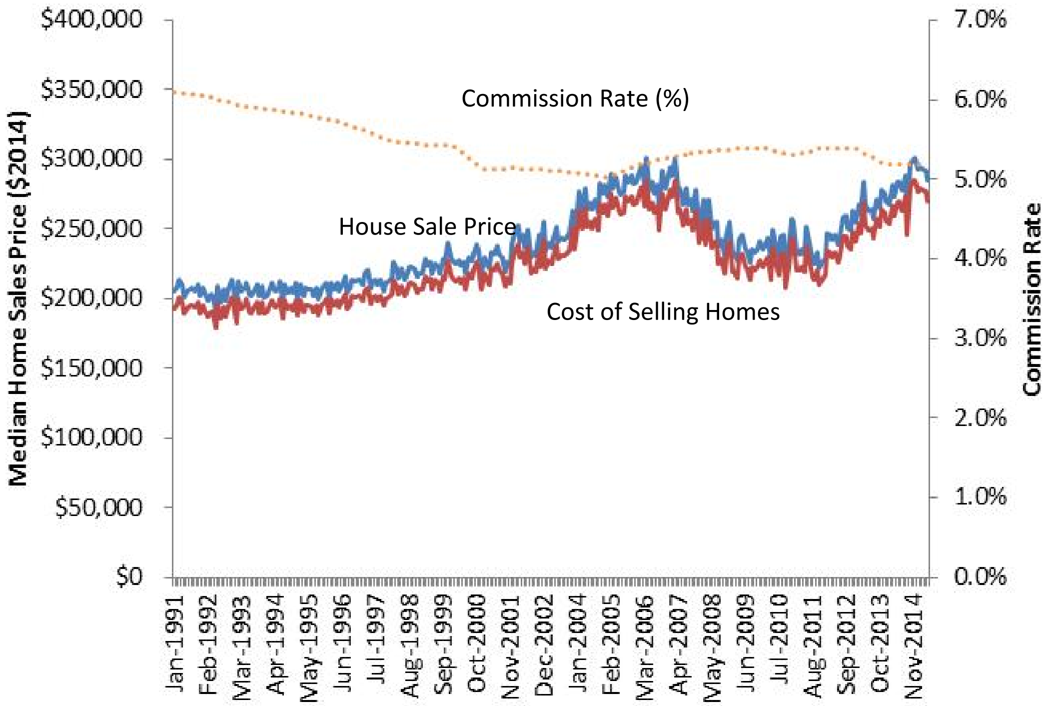

Figure 6A.2.5 House Sales Price, Costs of Selling Homes, and Realtor Commission (%)

After examining price and gross margin data in various markets, the results indicate that prices could go up or down in different of time, but the percent gross margins do not remain fixed over time. Hence, DOE does not expect that firms can sustain on applying constant markups on incremental costs of more efficient products after standards.

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APPENDIX 8A. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET

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APPENDIX 8A. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET

8A.1 INTRODUCTION

The detailed results of the life-cycle cost ("LCC") and payback period ("PBP") analysis are illustrated with a Microsoft Excel® spreadsheet, which is accessible on the U.S. Department of Energy's ("DOE") rulemaking website for miscellaneous refrigeration products ("MREFs").[a] The spreadsheet posted on the DOE website has been tested with Microsoft Excel 2016.

8A.2 DESCRIPTION OF LIFE-CYCLE COST SPREADSHEET

For all of the product classes, DOE created a single LCC workbook file containing a collection of worksheets. The LCC workbook contains the following worksheets that present results and sample calculations:

Summary	This worksheet contains a table of summary LCC and PBP results for all product classes ("PCs") at each efficiency level ("EL").
Cooler-FC **Cooler-F** **C3A** **C-13A** **C9**	Each of these worksheets contains detailed results and sample calculations for a single consumer (*i.e.,* a purchaser of an MREF) in the specified PC. Users can choose consumer characteristics with a series of drop-down menus and fillable cells. Users can also choose the no-new-standards case EL and the standards-case EL (*i.e.*, the standard level for the selected MREF product in the standards case). The right side of each sheet shows LCC and LCC savings results for the selected parameters.

The LCC workbook contains the following worksheets that present inputs used in the LCC and PBP analysis:

[a] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=39&action=viewlive

Sample Cooler-FC **Sample Cooler-F** **Sample C3A** **Sample C-13A** **Sample C9**	The PC-specific sample worksheets contain the samples of 10,000 consumers used in the LCC and PBP analysis. During a simulation, DOE uses these samples to derive results for the analysis.
Equipment Prices	This worksheet contains inputs for MREF product purchase prices for all representative MREF product units considered in the analysis. The information includes the manufacturer production cost ("MPC"), sales tax by census division and sector, as well as price markups.
Electricity	This worksheet shows the prices and price trends used to estimate electricity price for each consumer.
Discount Rates	This worksheet contains the distributions of discount rates.
Lifetime	This worksheet contains the survival probability distributions by product age for each of the PCs.
Market Distribution	This worksheet contains the no-new-standards market efficiency distribution for all PCs in the compliance year.
Energy Use	This worksheet contains the annual energy consumption by representative MREF product unit as provided by the Energy Use Analysis (see chapter 7 of this TSD).

APPENDIX 8B. UNCERTAINTY AND VARIABILITY

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APPENDIX 8B. UNCERTAINTY AND VARIABILITY

8B.1 INTRODUCTION

Analyzing a potential energy efficiency standard involves calculating its various effects, such as its effect on consumer life-cycle cost ("LCC") for products that have higher prices because of the new energy standard. To perform the calculation, the analyst must first:

1. specify the equation or model that will be used,
2. define the quantities in the equation or model, and
3. provide numerical values for each quantity.

In the simplest case, the equation is unambiguous—it contains all relevant quantities and no others; each quantity has a single numerical value; and the calculation produces a single value. Unambiguousness and precision are rarely the case, however. Usually the model and/or the numerical values for each quantity in the model are not completely known (*i.e.*, there is uncertainty), or the model and/or the numerical values for each quantity in the model depend on other conditions (*i.e.*, there is variability). Even given a single numerical value for each quantity in a calculation, arguments can arise about the appropriateness of each value.

Thorough analysis involves accounting for uncertainty and variability. Explicit analysis of uncertainty and variability provides more complete information to the decision-making process.

8B.2 UNCERTAINTY

When drawing conclusions about past events or speculating about the future, imperfect knowledge is the rule rather than the exception. For example, the energy consumed by a particular type of appliance (such as the average MREF) is not recorded directly, but rather estimated based on available information. Even direct laboratory measurements have a margin of error. When estimating numerical values for quantities at some future date, the exact outcome is rarely known.

8B.3 VARIABILITY

Specifying an exact value for a quantity is difficult if the value depends on other factors. Variability in the calculation of a quantity means that different applications or situations produce different numerical values. Variability makes it difficult to specify an appropriate value for an entire population, because no single value is likely to represent that entire population. Surveys can be helpful in such situations, and analysis of surveys can relate the variable of interest (such as hours of use) to other variables that are better known or easier to forecast (such as number of occupants per household).

8B.4 APPROACHES TO UNCERTAINTY AND VARIABILITY

Two approaches to uncertainty and variability are:

- scenario analysis, and
- probability analysis.

Scenario analysis uses a single numerical value for every quantity in a calculation, then changes one (or more) of those values and repeats the calculation. Numerous calculations are performed, providing some indication of the extent to which the result depends on each input. The LCC of an appliance, for example, can be calculated based on electricity costs of 2, 8, or 14 cents per kilowatt-hour.

The advantages of scenario analysis are that each calculation is simple; a range of estimates is considered; and crossover points can be identified. An example of a crossover point is the energy rate above which the LCC declines, holding all other inputs constant. In other words, the crossover point is the energy rate above which the consumer achieves savings in operating costs that more than compensate for the increased purchase price. The disadvantage of scenario analysis is that there is no information about the likelihood of any particular scenario.

Probability analysis considers the probability of each value within a range of values. To estimate the probability of each value for quantities characterized by variability (*e.g.*, electricity rates), survey data can be used to generate a frequency distribution of, for instance, the number of households subject to specific electricity rates. For quantities characterized by uncertainty, statistical or subjective measures can provide probabilities (*e.g.*, the manufacturing cost to improve an appliance's energy efficiency to a given level may be estimated to be $10 ± $3).

The major disadvantage of probability analysis is that it requires additional information about the shape and magnitude of the variability and the uncertainty of each quantity. The advantage of probability analysis is that it gives more information about the results of calculations by providing the probability that the result will be within a particular range.

Scenario and probability analyses provide some indication of the robustness of a policy given the identified uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of likely conditions and outcomes.

8B.5 PROBABILITY ANALYSIS AND THE USE OF MONTE CARLO SIMULATION IN THE LCC AND PBP ANALYSIS

To quantify the uncertainty and variability that exist in inputs to the LCC and PBP analysis, DOE used Monte Carlo simulation and probability distributions to conduct probability analyses.

Simulation refers to any analytical method meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Without the aid of simulation, a model will only reveal a single outcome, generally the most likely or average scenario. Probabilistic risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on the outputs of a modeled system. One type of simulation is Monte Carlo simulation, which repeatedly generates random values for uncertain variables, drawn from a probability distribution, to simulate a model.

For each uncertain variable, the range of possible values is controlled by a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. Probability distribution types include normal, triangular, uniform, and Weibull distributions, as well as custom distributions where needed. Example plots of these distributions are shown in Figure 8B.5.1.

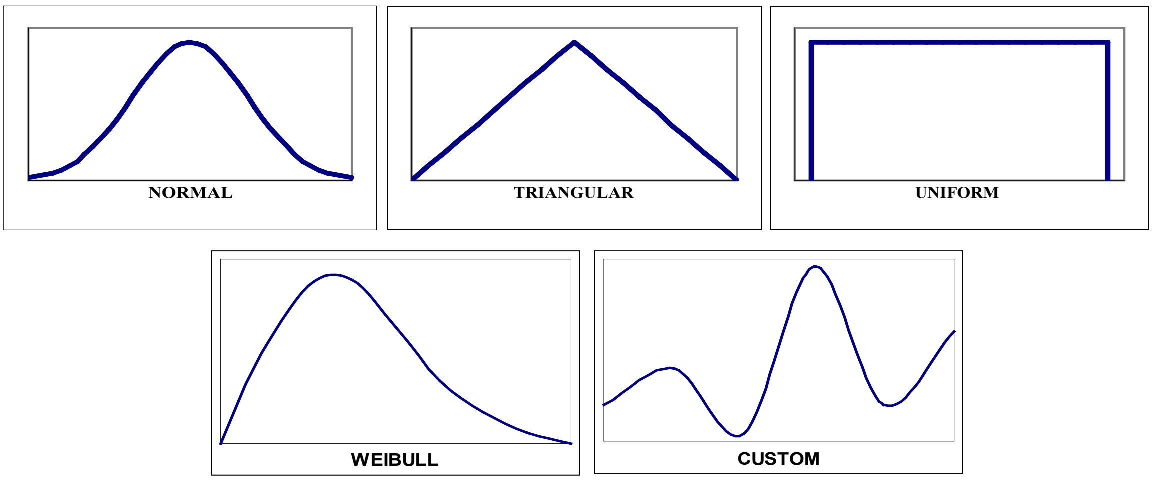

Figure 8B.5.1 Normal, Triangular, Uniform, Weibull, and Custom Probability Distributions

During a simulation, multiple scenarios are examined by repeatedly sampling values from the probability distributions for the uncertain variables. Simulations can consist of as many trials (or scenarios) as desired—hundreds or even thousands. For calculating the LCC for MREFs DOE performed 10,000 Monte Carlo simulations for each variable. During a single trial, a Python script randomly selected a value from the defined possibilities (the range and shape of the probability distribution) for each uncertain variable.

APPENDIX 8C. DISTRIBUTIONS USED FOR DISCOUNT RATES

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APPPENDIX 8C. DISTRIBUTIONS USED FOR DISCOUNT RATES

8C.1 INTRODUCTION: DISTRIBUTIONS USED FOR RESIDENTIAL CONSUMER DISCOUNT RATES

The Department of Energy ("DOE") derived consumer discount rates for the life-cycle cost ("LCC") analysis using data on interest or return rates for various types of debt and equity to calculate a real effective discount rate for each household in the Federal Reserve Board's *Survey of Consumer Finances* (*SCF*) in 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016, and 2019.[1] To account for variation among households in rates for each of the types, DOE sampled a rate for each household in its building sample from a distribution of discount rates for each of six income groups. This appendix describes the distributions used.

8C.1.1 Distribution of Rates for Equity Classes

Figure 8C.1.1 through Figure 8C.1.6 show the distribution of real interest rates for different types of equity. Data for equity classes are not available from the Federal Reserve Board's *SCF*, so DOE derived data for these classes from national-level historical data (1991-2020). The rates for stocks are the annual returns on the Standard and Poor's 500 for 1991–2020.[2] The interest rates associated with AAA corporate bonds were collected from Moody's time-series data for 1991–2020.[3] Rates on Certificates of Deposit ("CD"s) accounts came from Cost of Savings Index ("COSI") data covering 1991–2020.[4,a] The interest rates associated with state and local bonds (20-bond municipal bonds) were collected from Federal Reserve Board economic data time-series for 1991–2020.[9,b] The interest rates associated with treasury bills (30-Year treasury constant maturity rate) were collected from Federal Reserve Board economic data time-series for 1991–2020.[10,c] Rates for money market accounts are based on three-month money market account rates reported by Organization for Economic Cooperation and Development (OECD) from 1991–2020.[12] Rates for savings accounts are assumed to be half the average real money market rate. Rates for mutual funds are a weighted average of the stock rates and the bond rates.[d] The 30-year average nominal interest rates are shown in Table 8C.1.1. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year (see Figure 8C.1.7). In addition, DOE adjusted the nominal rates to real effective rates by accounting for the fact that interest on such equity types is taxable. The capital gains marginal tax rate varies for each household based on income as shown in chapter 8 (the impact of this is not shown in Figure 8C.1.1 through Figure 8C.1.6, which are only adjusted for inflation).

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[a] The Wells COSI is based on the interest rates that the depository subsidiaries of Wells Fargo & Company pay to individuals on certificates of deposit (CDs), also known as personal time deposits. Wells Fargo COSI started in November 2009.[5] From July 2007 to October 2009 the index was known as Wachovia COSI[6] and from January 1984 to July 2007 the index was known as GDW (or World Savings) COSI.[7,8]

[b] This index was discontinued in 2016. To calculate the 2017 and after values, DOE compared 1981-2020 data for 30-Year Treasury Constant Maturity Rate[10] and Moody's AAA Corporate Bond Yield[3] to the 20-Bond Municipal Bond Index data.[9]

[c] From 2003-2005 there are no data. For 2003-2005, DOE used 20-Year Treasury Constant Maturity Rate.[11]

[d] SCF reports what type of mutual funds the household has (e.g. stock mutual fund, savings bond mutual fund, etc.). For mutual funds with a mixture of stocks and bonds, the mutual fund interest rate is a weighted average of the stock rates (two-thirds weight) and the savings bond rates (one-third weight).

Table 8C.1.1 30-Year Average Nominal Interest Rates for Household Equity Type

Type of Equity	30 Year Average Nominal Rate *(%)*
Savings accounts	2.58
Money market accounts	2.84
Certificate of deposit	3.15
Treasury Bills (T-bills)	4.82
State/Local bonds	4.62
AAA Corporate Bonds	5.68
Stocks (S&P 500)	12.03
Mutual funds	9.63

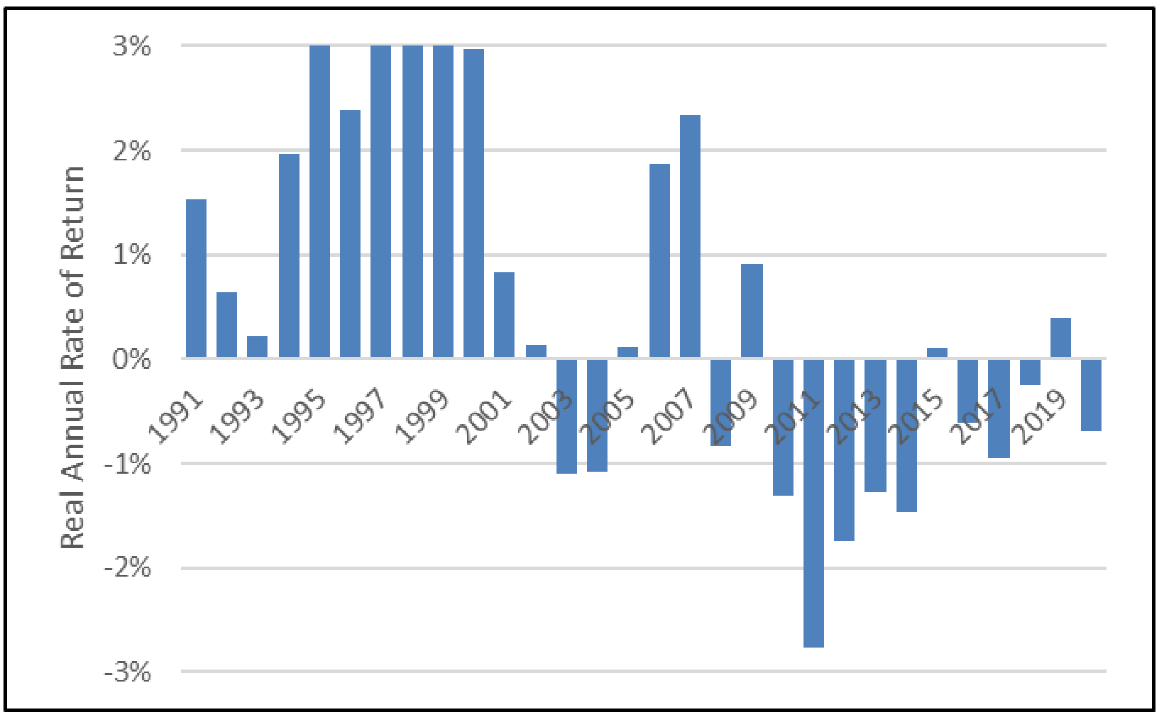

Figure 8C.1.1 Distribution of Annual Rate of Money Market Accounts

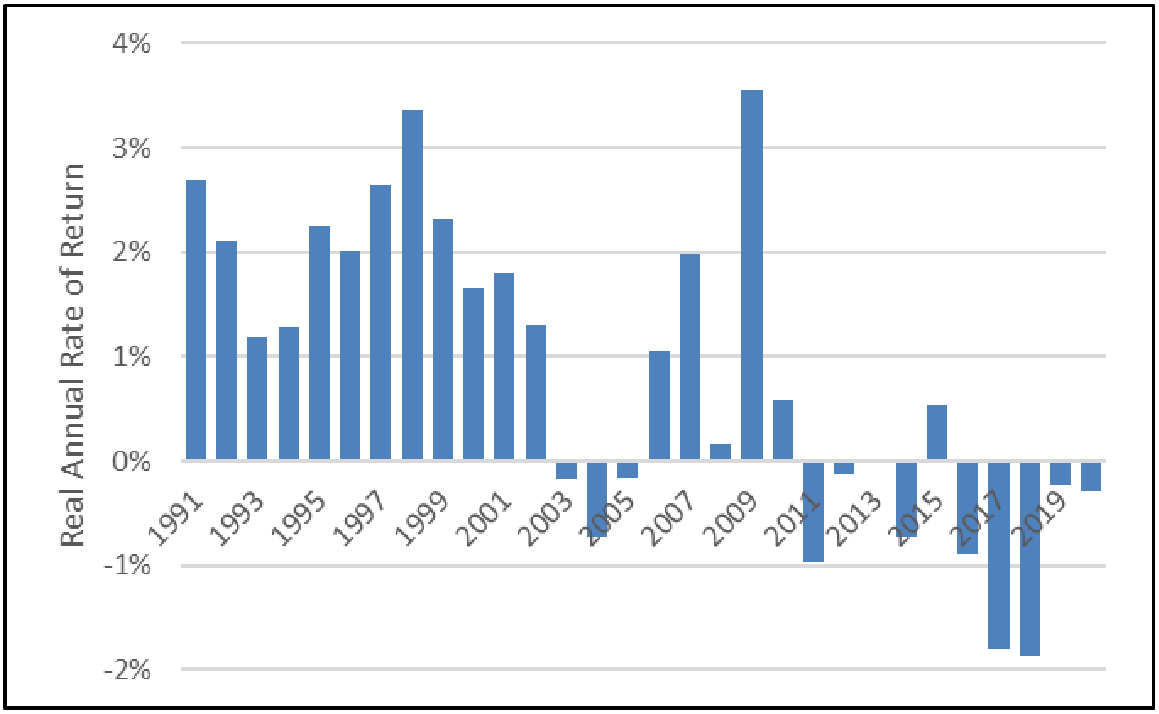

Figure 8C.1.2 Distribution of Annual Rate of Return on CDs

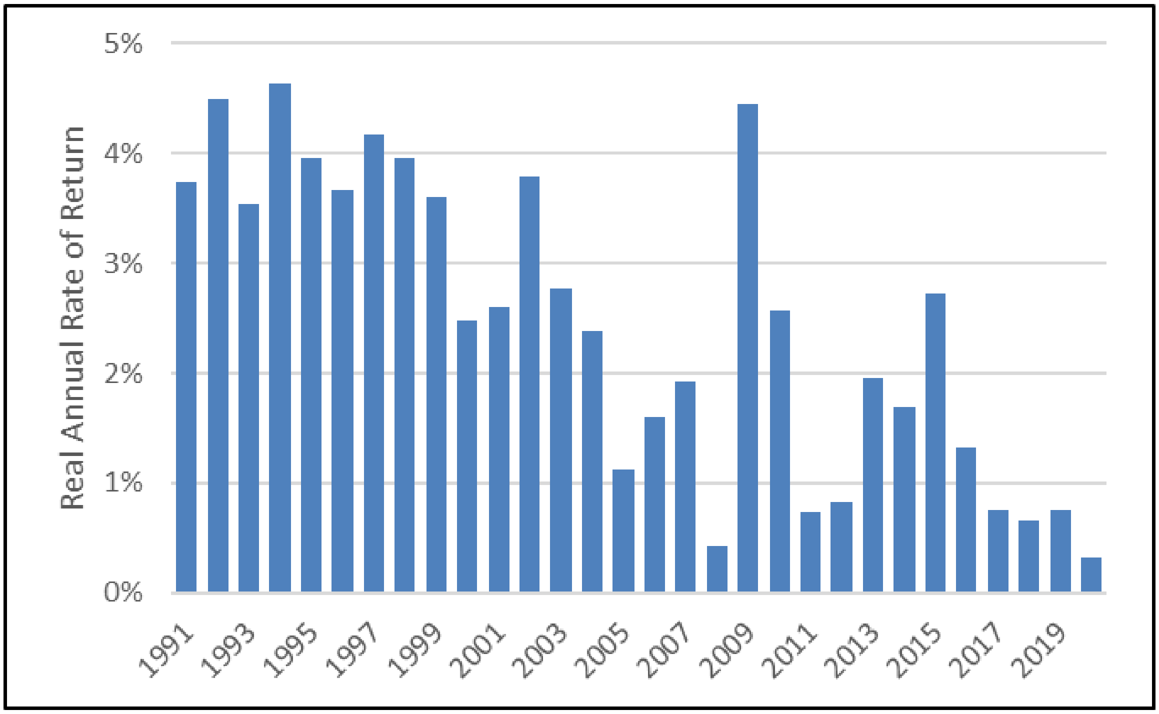

Figure 8C.1.3 Distribution of Annual Rate of Return on Savings Bonds (30 Year Treasury Bills)

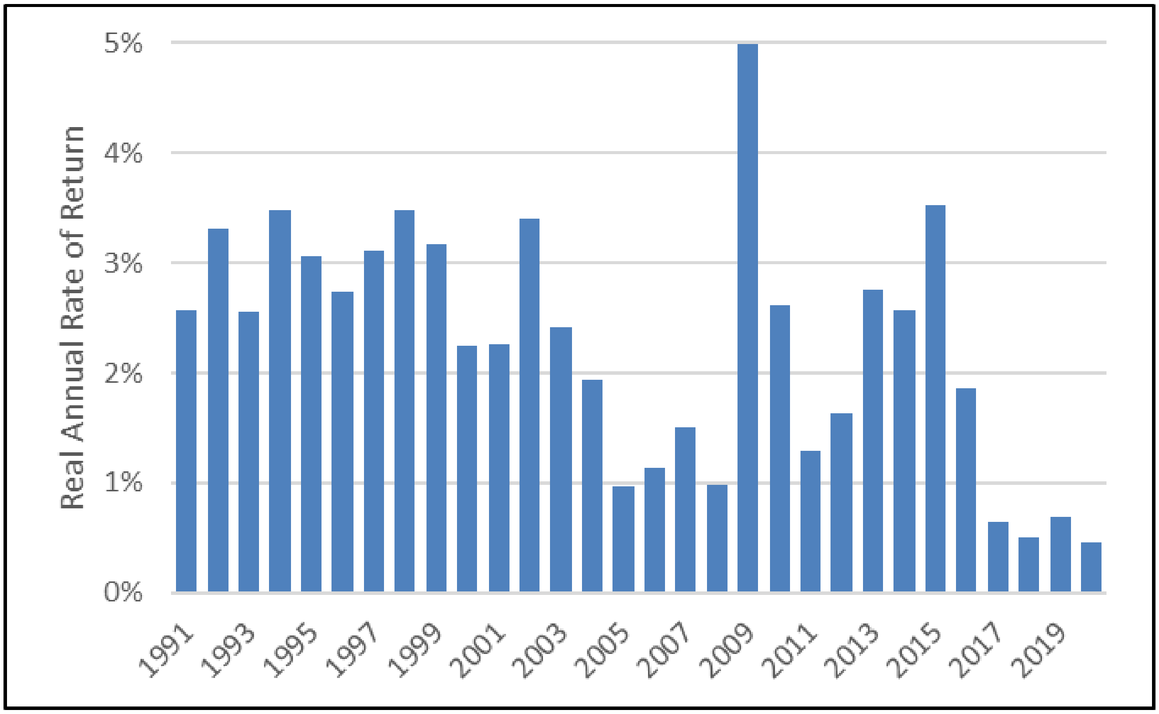

Figure 8C.1.4 Distribution of Annual Rate of State and Local Bonds

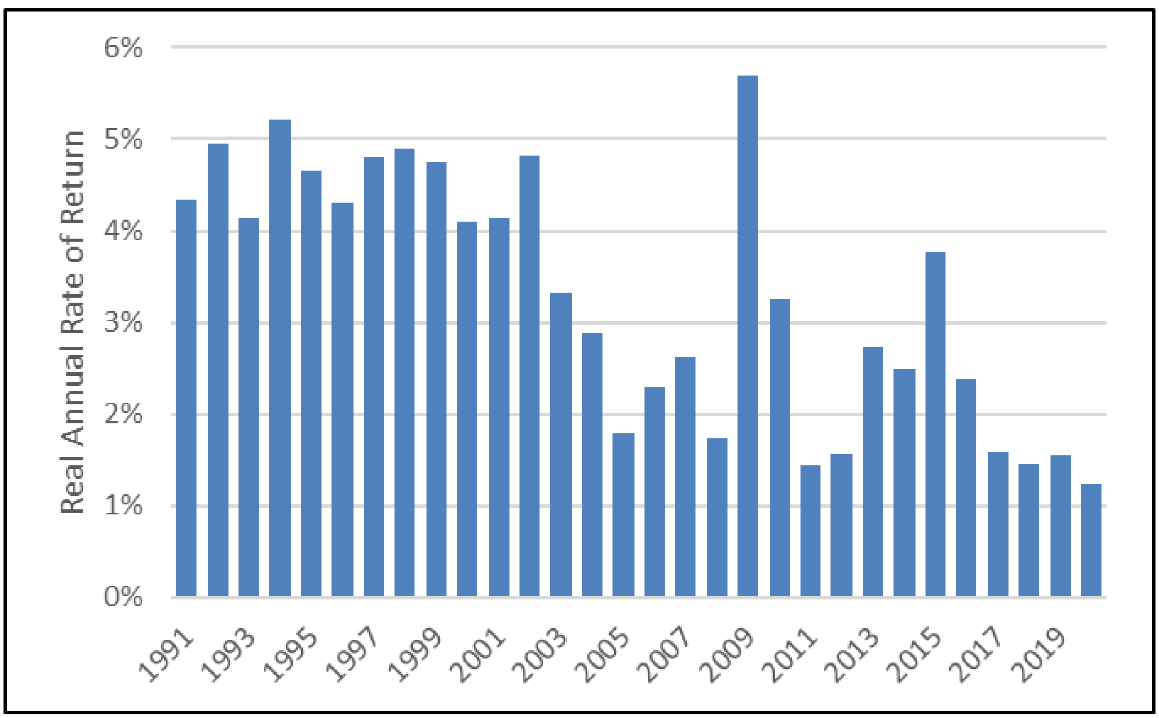

Figure 8C.1.5 Distribution of Annual Rate of Return on Corporate AAA Bonds

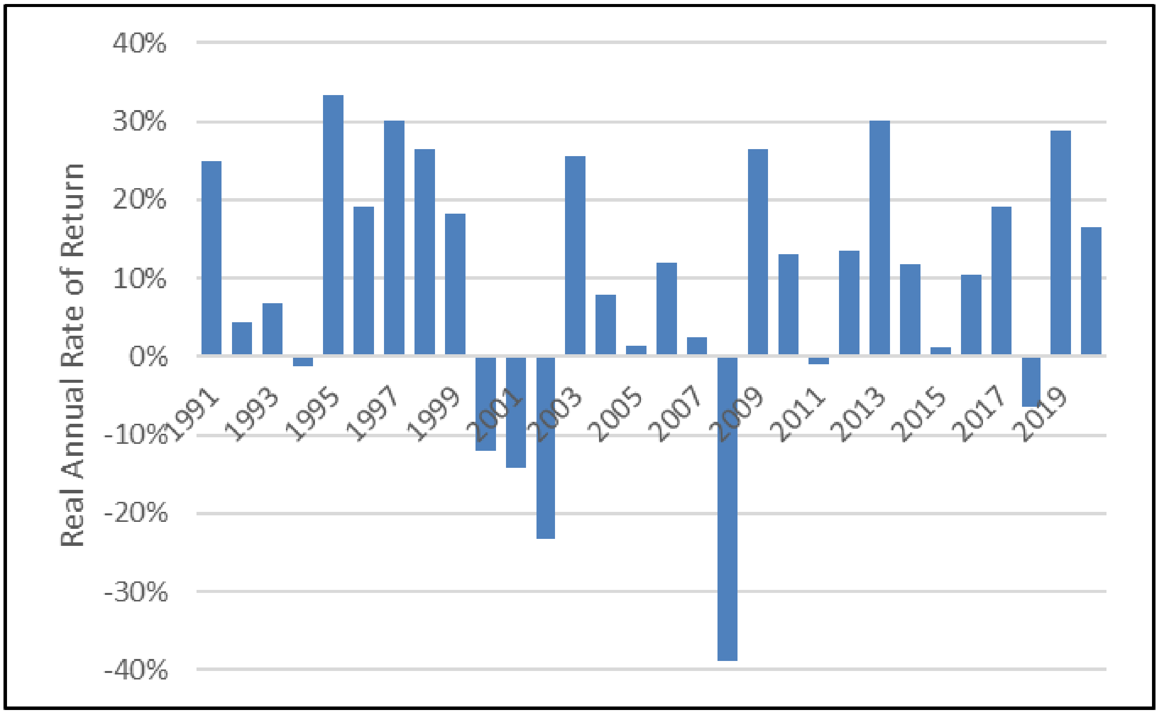

Figure 8C.1.6 Distribution of Annual Rate of Return on S&P 500

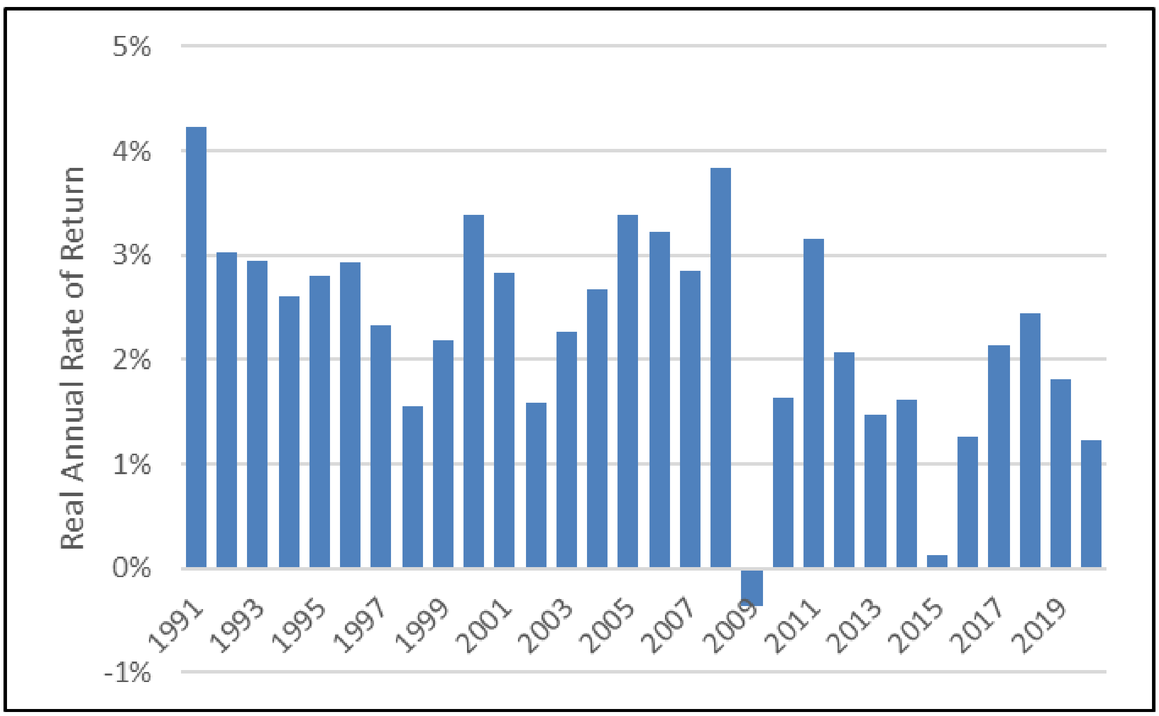

Figure 8C.1.7 Annual Consumer Price Index ("CPI") Rate

8C.2 DISTRIBUTION OF REAL EFFECTIVE DISCOUNT RATES BY INCOME GROUP

Real effective discount rates were calculated for each household of the SCF using the method described in Chapter 8. Interest rates for asset types were as described in 8C.1.1. The data source for the interest rates for mortgages, home equity loans, credit cards, installment loans, other residence loans, and other lines of credit is the Federal Reserve Board's *SCF* in 1995, 1998, 2001, 2004, 2007, 2010, 2013, 2016, and 2019. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year.

Using the appropriate *SCF* data for each year, DOE adjusted the nominal mortgage interest rate and the nominal home equity loan interest rate for each relevant household in the *SCF* for mortgage tax deduction and inflation. In cases where the effective interest rate is equal to or below the inflation rate (resulting in a negative real interest rate), DOE set the real effective interest rate to zero. Figure 8C.2.8 provides a graphical representation of the real effective discount rate distributions by income group, while Table 8C.2.1 provides the full distributions as used in the LCC analysis.

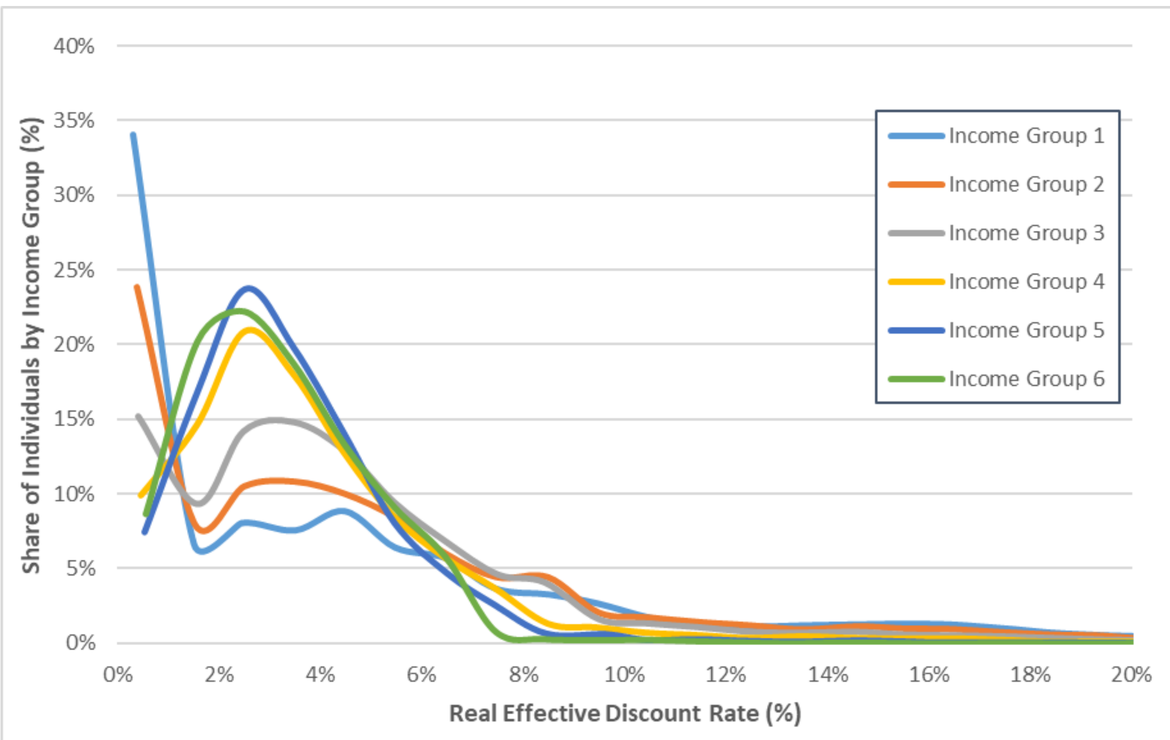

Figure 8C.2.8 Distribution of Real Discount Rates by Income Group

Table 8C.2.1 Distribution of Real Discount Rates by Income Group

DR Bin (%)	Income Group 1 (1-20 percentile)		Income Group 2 (21-40 percentile)		Income Group 3 (41-60 percentile)		Income Group 4 (61-80 percentile)		Income Group 5 (81-90 percentile)		Income Group 6 (90-99 percentile)	
	Rate %	Weight %	Rate %	Weight %	Rate %	Weight %	Rate %	Weight %	Rate %	Weight %	Rate %	Weight %
0-1	0.31	34.02	0.38	23.86	0.42	15.15	0.47	9.89	0.53	7.46	0.56	8.66
1-2	1.51	6.63	1.52	7.99	1.57	9.30	1.58	14.62	1.57	16.85	1.58	20.22
2-3	2.45	8.04	2.49	10.51	2.49	14.15	2.52	20.89	2.51	23.73	2.50	22.21
3-4	3.51	7.54	3.49	10.82	3.49	14.76	3.49	17.96	3.48	19.77	3.47	18.75
4-5	4.48	8.82	4.48	10.00	4.48	12.88	4.47	12.81	4.46	14.11	4.48	13.32
5-6	5.47	6.40	5.46	8.44	5.46	9.42	5.46	8.48	5.46	8.06	5.47	9.11
6-7	6.47	5.68	6.47	5.99	6.46	6.83	6.46	5.73	6.49	4.70	6.47	5.80
7-8	7.46	3.64	7.47	4.42	7.50	4.58	7.45	3.66	7.42	2.61	7.46	0.79
8-9	8.52	3.24	8.48	4.42	8.43	4.05	8.50	1.30	8.45	0.66	8.42	0.29
9-10	9.47	2.65	9.49	2.04	9.50	1.58	9.46	1.05	9.63	0.62	9.64	0.22
10-11	10.50	1.69	10.46	1.72	10.43	1.31	10.42	0.70	10.44	0.22	10.37	0.25
11-12	11.48	1.16	11.53	1.40	11.51	1.04	11.53	0.52	11.42	0.28	11.54	0.14
12-13	12.51	1.09	12.47	1.19	12.54	0.74	12.46	0.33	12.49	0.16	12.40	0.06
13-14	13.54	1.17	13.52	0.91	13.50	0.69	13.49	0.45	13.43	0.11	13.30	0.01
14-15	14.52	1.24	14.57	1.13	14.60	0.74	14.51	0.34	14.54	0.19	14.43	0.06
15-16	15.56	1.29	15.55	0.97	15.53	0.56	15.44	0.30	15.43	0.13	15.65	0.02
16-17	16.49	1.22	16.39	0.94	16.46	0.51	16.42	0.31	16.17	0.06	16.40	0.01
17-18	17.58	0.95	17.50	0.73	17.51	0.44	17.48	0.21	17.54	0.06	17.93	0.03
18-19	18.41	0.70	18.47	0.56	18.41	0.34	18.38	0.10	18.47	0.06	18.50	0.01
19-20	19.45	0.52	19.40	0.50	19.45	0.22	19.60	0.09	19.41	0.05	19.17	0.01
20-21	20.56	0.44	20.42	0.26	20.38	0.18	20.41	0.09	20.47	0.04	20.13	0.02
21-22	21.44	0.54	21.43	0.34	21.34	0.16	21.44	0.08	21.38	0.06	0.00	0.00
22-23	22.51	0.39	22.48	0.23	22.58	0.08	22.72	0.03	0.00	0.00	0.00	0.00
23-24	23.41	0.17	23.52	0.13	23.41	0.10	23.44	0.02	0.00	0.00	23.89	0.03
24-25	24.61	0.18	24.47	0.10	24.56	0.04	24.09	0.01	0.00	0.00	0.00	0.00
25-26	25.35	0.16	25.40	0.10	25.47	0.06	25.33	0.03	25.80	0.00	0.00	0.00
26-27	26.52	0.13	26.47	0.03	26.50	0.05	0.00	0.00	0.00	0.00	0.00	0.00
27-28	27.49	0.07	27.41	0.02	27.41	0.03	27.27	0.03	27.14	0.00	0.00	0.00
28-29	28.14	0.09	28.29	0.05	28.38	0.01	0.00	0.00	0.00	0.00	0.00	0.00
29-30	29.87	0.01	29.37	0.01	29.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
>30	68.17	0.14	125.34	0.19	135.29	0.02	53.85	0.00	0.00	0.00	0.00	0.00
Total	4.76	100.00	4.99	100.00	4.54	100.00	3.84	100.00	3.47	100.00	3.23	100.00

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APPENDIX 10A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSIS SPREADSHEET MODEL

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CHAPTER 10A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSIS SPREADSHEET MODEL

10A.1 USER INSTRUCTIONS

The results obtained in this analysis can be examined and reproduced using the Microsoft Excel® spreadsheets accessible on the Internet from the Department of Energy's ("DOE's") miscellaneous refrigeration products rulemaking page: www.regulations.gov/docket/EERE-2011-BT-STD-0043. From that page, follow the links to the preliminary analysis phase of the rulemaking and then to the analytical tools.

10A.2 STARTUP

The NIA spreadsheets enable the user to perform a National Impact Analysis ("NIA") for miscellaneous refrigeration products ("MREFs"). To utilize the spreadsheet, the Department assumed that the user would have access to a personal computer with a hardware configuration capable of running Windows 10 or later. To use the NIA spreadsheets, the user requires Microsoft Excel® 2013 or later installed under the Windows operating system.

10A.3 DESCRIPTION OF NATIONAL IMPACT ANALYSIS WORKSHEETS

The NIA spreadsheets perform calculations to project the change in national energy use and net present value of financial impacts due to revised energy efficiency standards. The energy use and associated costs for a given standard level are determined by calculating the shipments and then calculating the energy use and costs for all MREFs shipped under that standard. The differences between the standards and base case can then be compared and the overall energy savings and net present values ("NPV") determined. The NIA spreadsheets consist of the following major worksheets as shown in Table 10A.3.1.

Table 10A.3.1 Description of NIA Spreadsheet Worksheets

Worksheet	Description
Summary	Contains a summary of disaggregated NIA results for all product classes at the selected trial standard level (TSL).
Freestanding Compact Coolers	Contains NIA calculations for freestanding compact coolers.
Built in Compact Coolers	Contains NIA calculations for built-in compact coolers.
Freestanding Coolers	Contains NIA calculations for freestanding coolers.
Built-in Coolers	Contains NIA calculations for built-in coolers.
Combination 3A	Contains NIA calculations for combination 3A.
Combination 3A-BI	Contains NIA calculations for combination 3A-BI.
Combination 9	Contains NIA calculations for combination 9.
Combination 9-BI	Contains NIA calculations for combination 9-BI.
Combination 13A	Contains NIA calculations for combination 13A.
Combination 13A-BI	Contains NIA calculations for combination 13A-BI.
PC Inputs	Contains energy use, retail price, installation cost, and annual repair and maintenance costs for each efficiency level.
Shipments	Contains historical and projected shipments data for each product class.
Energy Factors	Contains energy conversion factors for NIA calculations.
Energy Price	Contains energy prices for each product class by year for the reference, high growth, and low growth AEO scenarios.
Lifetime	Includes the survival probabilities by year for each product class.

10A.4 BASIC INSTRUCTIONS FOR OPERATING THE NATIONAL IMPACT ANALYSIS SPREADSHEETS

Basic instructions for operating the NIA spreadsheets are as follows:

1. Once the NIA spreadsheet file has been downloaded from the Department’s website, open the file using MS Excel. Click “Enable Editing” when prompted and then click on the tab for the worksheet User Inputs.

2. Use MS Excel’s View/Zoom commands at the top menu bar to change the size of the display to make it fit your monitor.

3. The user can change the parameters in the sheet “Summary”. (Note that all the results in the “Summary” worksheet are for the selected TSL.) The default parameters (shown in Figure 10A.4.1) are:

Economic Growth	Reference
Discount Rate	7%
Analysis Period	Full
Energy Savings	Site
TSL	1
Results	Prod Group

Figure 10A.4.1 Default User Input Parameters (Summary) for NIA Spreadsheets

a) Economic Growth: Set to "Reference". To change value, click on the drop down menu next to cell "Economic Growth" and change to desired scenario ("Reference", "High", or "Low").

b) Discount Rate: Set to "7%". To change value, click on the drop down menu next to the cell "Discount Rate" and change to desired value ("7%" or "3%").

c) Analysis Period: Set to "Full". To change value, click on the drop down menu next to the cell "Analysis Period" and change to desired analysis period ("Full" (30 years) or "Short" (9 years)).

d) Energy Savings: Set to "FFC". To change value, click on the drop down menu next to the cell "Energy Savings" and change to desired value ("Site", "Primary", or "FFC").

e) TSL: Set to "1". To change the value, click on the drop down menu next to cell "TSL" and change to desired TSL ("1", "2", "3", "4", or "5").

4. The user can view the summarized results (NPV and energy savings) for the selected Trial Standard Level (TSL) in the "Summary" sheet (one example is shown in Figure 10A.4.2).

National		*Freestanding Compact Coolers*
NPV	*mi 2020$*	296.4
Incr Equipment Costs	*mi 2020$*	84.4
Operating Cost Savings	*mi 2020$*	380.8
Site Energy Savings	*quads*	0.0
Electricity	*quads*	0.0
Perc of BC Consumption	%	14.4%

Figure 10A.4.2 NIA Results Summary for Freestanding Compact Coolers

Make sure that the spreadsheet is in automatic calculation mode. The calculation mode could be changed by (shown in Figure 10A.4.3):

1. In Excel 2013 and later, go to the tab "Formulas" in the Office ribbon.
2. Click on the button "Calculation Options" and select "Automatic".

The results are automatically updated and are reported in the source energy savings matrix, net present value matrix, and summary table for each product class.

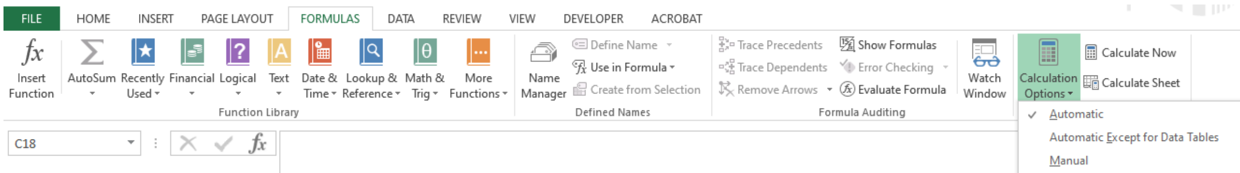

Figure 10A.4.3 Set the Spreadsheet to Automatic Calculation Mode

APPENDIX 10B. FULL-FUEL-CYCLE ANALYSIS

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APPENDIX 10B. FULL-FUEL-CYCLE ANALYSIS

10B.1 INTRODUCTION

This appendix summarizes the methods the U.S. Department of Energy ("DOE") used to calculate the estimated full-fuel-cycle ("FFC") energy savings from potential energy conservation standards. The FFC measure includes point-of-use (site) energy; the energy losses associated with generation, transmission, and distribution of electricity; and the energy consumed in extracting, processing, and transporting or distributing primary fuels. DOE's method of analysis previously encompassed only site energy and the energy lost through generation, transmission, and distribution of electricity. In 2011 DOE announced its intention, based on recommendations from the National Academy of Sciences, to use FFC measures of energy use and emissions when analyzing proposed energy conservation standards.[1] This appendix summarizes the methods DOE used to incorporate impacts of the full fuel cycle into the analysis.

In the national energy savings calculation, DOE estimates the site, primary and FFC energy consumption for each standard level, for each year in the analysis period. DOE defines these quantities as follows:

- Site energy consumption is the physical quantity of fossil fuels or electricity consumed at the site where the end-use service is provided.[a] The site energy consumption is used to calculate the energy cost input to the NPV calculation.
- Primary energy consumption is defined by converting the site fuel use from physical units, for example cubic feet for natural gas, or kWh for electricity, to common energy units (million Btu or MMBtu). For electricity the conversion factor is a marginal heat rate that incorporates losses in generation, transmission and distribution, and depends on the sector, end use and year.
- The FFC energy use is equal to the primary energy use plus the energy consumed "upstream" of the site in the extraction, processing and distribution of fuels. The FFC energy use was calculated by applying a fuel-specific FFC energy multiplier to the primary energy use.

For electricity from the grid, site energy is measured in terawatt-hours (TWh). The primary energy of a unit of grid electricity is equal to the heat content of the fuels used to generate that electricity, including transmission and distribution losses.[b] DOE typically measures the primary energy associated with the power sector in quads (quadrillion Btu). Both primary fuels and electricity are used in upstream activities. The treatment of electricity in full-fuel-cycle analysis must distinguish between electricity generated by fossil fuels and electricity generated

[a] For fossil fuels, this is the site of combustion of the fuel.
[b] For electricity sources like nuclear energy and renewable energy, the primary energy is calculated using the convention described below.

from renewable sources (wind, solar, and hydro). For the former, the upstream fuel cycle relates to the fuel consumed at the power plant. There is no upstream component for the latter, because no fuel *per se* is used.

10B.2 SITE-TO-PRIMARY ENERGY FACTORS

DOE uses heat rates to convert site electricity savings in TWh to primary energy savings in quads. The heat rates are developed as a function of the sector, end-use and year of the analysis period. For this analysis DOE uses output of the DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[2] EIA uses the NEMS model to produce the *Annual Energy Outlook* (*AEO*). DOE's approach uses the most recently available edition, in this case *AEO 2021*.[3] The *AEO* publication includes a reference case and a series of side cases incorporating different economic and policy scenarios. DOE calculates marginal heat rates as the ratio of the change in fuel consumption to the change in generation for each fossil fuel type, where the change is defined as the difference between the reference case and the side case. DOE calculates a marginal heat rate for each of the principal fuel types: coal, natural gas and oil. DOE uses the EIA convention of assigning a heat rate of 10.5 Btu/Wh to nuclear power and 9.5 Btu/Wh to electricity from renewable sources.

DOE multiplied the fuel share weights for sector and end-use, described in appendix 15A of this TSD, by the fuel specific marginal heat rates, and summed over all fuel types, to define a heat rate for each sector/end-use. This step incorporates the transmission and distribution losses. In equation form:

$$h(u,y) = (1 + TDLoss)*\sum_{r,f} g(r,f,y)\, H(f,y)$$

Where:

$TDLoss$ = the fraction of total generation that is lost in transmission and distribution, equal to 0.07037
u = an index representing the sector/end-use (e.g. commercial cooling)
y = the analysis year
f = the fuel type
$H(f,y)$ = the fuel-specific heat rate
$g(r,f,y)$ = the fraction of generation provided by fuel type f for end-use u in year y
$h(u,y)$ = the end-use specific marginal heat rate

The sector/end-use specific heat rates are shown in Table 10B.2.1. These heat rates convert site electricity to primary energy in quads; i.e., the units used in the table are quads per TWh.

Table 10B.2.1 Electric Power Heat Rates (MMBtu/MWh) by Sector and End-Use

	2025	2030	2035	2040	2045	2050+
Residential						
Clothes Dryers	9.484	9.258	9.257	9.205	9.153	9.133
Cooking	9.473	9.246	9.245	9.193	9.142	9.122

Freezers	9.496	9.267	9.264	9.211	9.159	9.138
Lighting	9.511	9.289	9.290	9.238	9.186	9.167
Refrigeration	9.496	9.267	9.264	9.212	9.159	9.138
Space Cooling	9.397	9.146	9.133	9.080	9.026	9.001
Space Heating	9.526	9.306	9.308	9.256	9.204	9.185
Water Heating	9.493	9.270	9.271	9.219	9.168	9.149
Other Uses	9.484	9.259	9.258	9.206	9.154	9.134
Commercial						
Cooking	9.409	9.184	9.185	9.135	9.085	9.065
Lighting	9.426	9.200	9.200	9.150	9.100	9.079
Office Equipment (Non-Pc)	9.374	9.145	9.145	9.095	9.046	9.026
Office Equipment (Pc)	9.374	9.145	9.145	9.095	9.046	9.026
Refrigeration	9.476	9.250	9.249	9.197	9.146	9.126
Space Cooling	9.378	9.125	9.111	9.058	9.005	8.979
Space Heating	9.532	9.313	9.314	9.262	9.210	9.191
Ventilation	9.478	9.253	9.252	9.200	9.149	9.129
Water Heating	9.409	9.184	9.186	9.136	9.087	9.067
Other Uses	9.389	9.161	9.162	9.111	9.062	9.042
Industrial						
All Uses	9.389	9.161	9.162	9.111	9.062	9.042

10B.3 FFC METHODOLOGY

The methods used to calculate FFC energy use are summarized here. The mathematical approach to determining FCC is discussed in Coughlin (2012).[4] Details related to the modeling of the fuel production chain are presented in Coughlin (2013).[5]

When all energy quantities are normalized to the same units, FFC energy use can be represented as the product of the primary energy use and an FFC multiplier. Mathematically the FFC multiplier is a function of a set of parameters that represent the energy intensity and material losses at each stage of energy production. Those parameters depend only on physical data, so the calculations require no assumptions about prices or other economic factors. Although the parameter values may differ by geographic region, this analysis utilizes national averages.

The fuel cycle parameters are defined as follows.

- a_x is the quantity of fuel x burned per unit of electricity produced for grid electricity. The calculation of a_x includes a factor to account for losses incurred through the transmission and distribution systems.
- b_y is the amount of grid electricity used in producing fuel y, in MWh per physical unit of fuel y.
- c_{xy} is the amount of fuel x consumed in producing one unit of fuel y.
- q_x is the heat content of fuel x (MBtu/physical unit).

All the parameters are calculated as functions of an annual time step; hence, when evaluating the effects of potential new standards, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period and cumulatively.

The FFC multiplier is denoted μ (mu). A separate multiplier is calculated for each fuel used on site. Also calculated is a multiplier for electricity that reflects the fuel mix used in its generation. The multipliers are dimensionless numbers applied to primary energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to (μ-1). The fuel type is denoted by a subscript on the multiplier μ.

The method for performing the full-fuel-cycle analysis utilizes data and projections published in the *AEO 2021*. Table 10B.3.1 summarizes the data used as inputs to the calculation of various parameters. The column titled "*AEO* Table" gives the name of the table that provided the reference data.

Table 10B.3.1 Dependence of FFC Parameters on *AEO* Inputs

Parameter(s)	Fuel(s)	*AEO* Table	Variables
q_x	All	Conversion factors	MMBtu per physical unit
a_x	All	Electricity supply, disposition, prices, and emissions Energy consumption by sector and source	Generation by fuel type Electric energy consumption by the power sector
b_c, c_{nc}, c_{pc}	Coal	Coal production by region and type	Coal production by type and sulfur content
b_p, c_{np}, c_{pp}	Petroleum	Refining industry energy consumption Liquid fuels supply and disposition International liquids supply and disposition Oil and gas supply	Refining-only energy use Crude supply by source Crude oil imports Domestic crude oil production
c_{nn}	Natural gas	Oil and gas supply Natural gas supply, disposition, and prices	U.S. dry gas production Pipeline, lease, and plant fuel
z_x	All	Electricity supply, disposition, prices, and emissions	Power sector emissions

The *AEO 2021* does not provide all the information needed to estimate total energy use in the fuel production chain. Coughlin (2013) describes the additional data sources needed to complete the analysis. The time dependence in the FFC multipliers, however, arises exclusively from variables taken from the *AEO*.

10B.4 ENERGY MULTIPLIERS FOR THE FULL FUEL CYCLE

FFC energy multipliers for selected years are presented in Table 10B.4.1. The 2050 value was held constant for the analysis period beyond 2050, which is the last year in the *AEO 2021* projection. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation throughout the forecast period.

Table 10B.4.1 Energy Multipliers for the Full Fuel Cycle (Based on *AEO 2021*)

	2025	**2030**	**2035**	**2040**	**2045**	**2050+**
Electricity	1.042	1.039	1.038	1.037	1.038	1.037

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