Energy Conservation Standards
Rulemaking Framework Document for
Commercial and Industrial Pumps

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Building Technologies Program

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AEC	annual energy consumption
AEO	*Annual Energy Outlook*
ANSI	American National Standard Institute
API	American Petroleum Institute
BEP	best efficiency point
BLS	Bureau of Labor Statistics
BT	Building Technologies Program
CAIR	Clean Air Interstate Rule
CAMR	Clean Air Mercury Rule
CFD	computational fluid dynamic
CFR	Code of Federal Regulations
CO_2	carbon dioxide
CSL	candidate standard level
DOE	U.S. Department of Energy
DOJ	U.S. Department of Justice
EERE	Office of Energy Efficiency and Renewable Energy
EGU	electricity generating unit
EIA	Energy Information Administration
EISA	Energy Independence and Security Act of 2007
EPA	U.S. Environmental Protection Agency
EPCA	Energy Policy and Conservation Act
EU	European Union
FFC	full-fuel cycle
FR	Federal Register
GHG	greenhouse gas
gpm	gallons per minute
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GRIM	Government Regulatory Impact Model
HAP	hazardous air pollutant
Hg	mercury
HI	Hydraulic Institute
HP	horsepower
HVAC	heating, ventilating, and air conditioning
ImSET	Impact of Sector Energy Technologies
ISO	International Organization for Standardization
kg	kilograms
kW	kilowatt
LCC	life-cycle cost
MEI	minimum efficiency index
MPC	manufacturer production cost
MSP	manufacturer selling price
MIA	manufacturer impact analysis
NIA	national impact analysis
NEMS	National Energy Modeling System

NES	national energy savings
NESHAPs	national emissions standards for hazardous air pollutants
NOPR	notice of proposed rulemaking
NO_X	oxides of nitrogen
NPSH	net positive suction head
NPV	net present value
OEM	original equipment manufacturer
OMB	Office of Management and Budget
PBP	payback period
PM	particulate matter
R&D	research and development
RFI	request for information
rpm	revolutions per minute
SCC	social cost of carbon
SG&A	selling, general, and administrative costs
SO_2	sulfur dioxide
TSD	technical support document
TSL	trial standard level
U.S.	United States
U.S.C.	United States Code
VSD	variable speed drive

1. INTRODUCTION

The U.S. Department of Energy (DOE) Appliances and Equipment Standards Program, within the Office of Energy Efficiency and Renewable Energy's Building Technologies Program (BT), develops and promulgates test procedures and energy conservation standards for certain consumer appliances and commercial and industrial equipment. The process for developing standards involves analysis, public notice and comment, and consultation with interested parties. Interested parties include manufacturers, consumers, energy conservation and environmental advocates, State and Federal agencies, and any other groups or individuals having an interest in these standards and test procedures.

The purpose of this framework document is to describe the procedural and analytical approaches DOE anticipates using to evaluate potential new energy conservation standards for pumps. This framework document is intended to inform interested parties of the process DOE will follow for the standards rulemaking for pumps and to encourage and facilitate the input of interested parties during the rulemaking. This document is merely the starting point for evaluating energy conservation standards or energy use standards and is not a definitive statement on any issue to be determined in the rulemaking.

This framework document is organized in the following manner. Section 1.1 describes the statutory authority for this rulemaking. Section 1.2 provides an overview of the scope of coverage DOE is considering, section 1.3 discusses equipment definitions, section 1.4 discusses metrics used to describe pump efficiency, and section 1.5 discusses test procedure methods that could be used to measure pump efficiency. Section 1.6 provides an overview of DOE's rulemaking process, and section 2 describes the analyses that DOE conducts, which are described further in sections 3 through 17.

DOE will analyze pumps to determine whether new energy conservation standards are technologically feasible and economically justified and would result in significant energy savings. DOE will maintain information about this rulemaking on its Office of Energy Efficiency and Renewable Energy (EERE) website at: http://www1.eere.energy.gov/buildings/appliance_standards/commercial/commercial_industrial_pumps.html.

While DOE invites comment on all aspects of the material presented in this document, several specific issues on which DOE seeks comment are set out in comment boxes like this one. DOE uses these comment boxes to highlight issues and ask specific questions on the approaches DOE plans to follow to conduct the analyses required for the energy conservation standards rulemaking. Such requests for feedback are numbered sequentially throughout the document and are listed in appendix A.

1.1 Authority and Background

Title III of the Energy Policy and Conservation Act of 1975 (EPCA), as amended (42 U.S.C. 6291 et seq.), sets forth various provisions designed to improve energy efficiency. Part C of Title III of EPCA (42 U.S.C. 6311-6317) (re-designated as part A-1 upon codification in the U.S. Code), establishes the "Energy Conservation Program for Certain Industrial Equipment," which covers certain commercial and industrial equipment (hereafter referred to as "covered equipment").

EPCA specifies a list of equipment that constitutes covered commercial and industrial equipment, including pumps. (42 U.S.C. 6311(1)(A)). In considering whether to establish standards for pumps, DOE issued a Request for Information (RFI) on June 13, 2011. (76 FR 34192). DOE received comments from stakeholders, which are available in the rulemaking docket (EERE-2011-BT-STD-0031)[1] and have been considered in developing this framework. In December 2011, DOE received a letter from the Appliance Standards Awareness Project (ASAP) and the Hydraulic Institute indicating that efficiency advocates (including ASAP, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, and Northwest Energy Efficiency Alliance) and pump manufacturers (as represented by the Hydraulic Institute), had initiated discussions regarding potential energy conservation standards for commercial and industrial pumps. In subsequent letters in March and April 2012, and in a meeting with DOE in May 2012[2], the stakeholders reported on a tentative path forward on three items: energy conservation standards for water pumps, certification and labeling, and an “extended product” approach. These items are expanded upon in relevant sections of this document.

1.2 Pumps for which DOE is Considering Standards

Commercial and industrial pumps cover a wide range of equipment and applications. In this rulemaking, DOE is considering energy conservation standards for a subset of available pumps that accounts for a significant share of energy use, as described in 1.2.1. Standards could be established for additional types of pumps in this or a future rulemaking.

1.2.1 Pump Types

1.2.1.1 Clean Water Pumps

While numerous pump types exist for commercial and industrial applications, DOE is considering standards for pumps designed for clean water. This approach is consistent with the European Union (EU) regulation for water pumps [1]. The stakeholders also expressed agreement on pursuing standards for clean water pumps based on the EU regulation.

DOE is considering standards for clean water pumps because industry standard pump tests use clean water only, and most published pump performance curves are based on clean water. DOE notes that testing with some fluids other than water may cause additional manufacturer burden. The American National Standard Institute (ANSI) and the Hydraulic Institute (HI) standard, ANSI/HI 12.6-2011 (Rotodynamic [Centrifugal] Slurry Pumps), notes that “Slurry tests are expensive and, therefore, should only be considered for extremely critical services where there is no other alternative

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[1] http://www.regulations.gov/#!docketDetail;D=EERE-2011-BT-STD-0031;dct=FR%252BPR%252BN%252BO%252BSR

[2] The December 2011, March 2012, and April 2012 letters are available for review in the rulemaking docket. A memorandum memorializing the May 2012 meeting is available in the docket and at: http://energy.gov/sites/prod/files/Ex_Parte_Memo_ASAP_%26_HI_5_10_2012.pdf.

[2].” In addition, even where test procedures are possible for other fluids, setting standards for pumps using many fluids could be difficult.

As part of this rulemaking, DOE will consider developing a definition for ‘clean water’ that may include suspended and dissolved solids limits high enough to cover most pumps designed for water that may not typically be considered clean, such as river water, sea water, or brackish water (see section 1.3). Alternatively, DOE may define “pumps designed for clean water” based on physical characteristics of the pumps, such as the following:

- metallurgy,
- Sealing (or sealless) technology (depending on pressure and temperature limits),
- impeller type[3] (*i.e.,* slurry, vortex, recessed impeller),
- replaceable wear plates,
- barrel casing, and
- center-line support.[4]

DOE understands that sump and slurry pumps and solids-handling type pumps are rarely used for clean water. The EU Lot 28[5] process proposes covering a large number of pump types for these applications and will likely define classes of wastewater for which manufacturers would have to guarantee efficiency [3]. However, testing may be based on clean water, with efficiency for the classes of wastewater based on relationships between clean water and the given wastewater. DOE is considering not covering these pumps in the current rulemaking.

However, DOE also understands that other types of pumps not primarily designed for clean water, such as ANSI chemical process pumps, may also be used to pump clean water. These pumps are generally designed for other liquids that contain no solids, are aqueous, and would behave similarly to water in terms of their effect on pump efficiency. They are also tested with clean water. Not regulating them may simply represent a lost energy savings opportunity, particularly if standards for other pumps result in increased sales of these unregulated pumps. DOE requests comment on whether such pumps should be covered or if they should be excluded based on their certifications or certain design characteristics, such as those listed above. DOE recognizes that pumps designed to meet the American Petroleum Institute (API) 610 standard (for hydrocarbon products) may have safety requirements (larger clearances) that result in reduced efficiency [3]. In addition, DOE understands API 610 pumps to be extremely cost-prohibitive for water applications. As such, DOE is not considering standards for API 610 pumps in this framework document, but welcomes comment on this issue.

Item 1-1 DOE seeks comment on its proposal to cover only clean water pumps in this rulemaking.

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[3] DOE may exclude pumps with slurry, vortex, and recessed impellers. However, DOE is considering standards for pumps with open impellers in this framework document.

[4] DOE also considered shaft sleeves, bearing weight, and pump-out vanes on the back side of an impeller, but determined that these characteristics have some functions not related to the liquid being pumped.

[5] The European Union (EU) Lot 28 Ecodesign Directive proposes coverage of pumps for private and public waste water and for fluids with high solid content.

Item 1-2 DOE requests comment on whether it should rely on a definition of 'clean water' to determine coverage of pumps, as in the EU, or if, instead, the definition of 'clean water pumps' should include physical characteristics that distinguish pumps designed for clean water or exclude pumps designed for other purposes.

Item 1-3 DOE seeks comment on the list of physical differences that may exist between pumps designed for clean water and pumps designed for other substances. Specifically, (1) is the list accurate and exhaustive, (2) do the differences impact efficiency, and (3) do the differences have increased cost?

Item 1-4 DOE seeks comment on whether it should consider standards for pumps designed for non-water liquids that contain limited solids in this rulemaking. DOE is specifically interested in ANSI chemical process pumps, API 610 pumps, sealless (magnetic drive, canned, or cantilever) pumps, sanitary pumps, refrigerant pumps, and general industrial pumps. When suggesting pump types for which standards should not be considered, please be specific as to the reason why.

Item 1-5 DOE requests comment on whether any design changes made to standard clean water pumps would carry through to pumps designed for other applications.

1.2.1.2 Rotodynamic Pumps

There are two broad categories of pumps: rotodynamic and positive displacement. In this framework document, DOE is considering energy conservation standards for rotodynamic pumps. This is the approach used in the EU regulations[6], and the stakeholders also expressed support for this approach. Rotodynamic pumps represent approximately 70 percent of industrial pump sales by value [4] and 90 percent of pump energy use [5]. Positive displacement pumps represent a small percentage of the market and are generally used for niche applications such as viscous or shear-sensitive liquids. Because positive displacement pumps and rotodynamic pumps provide different utility, technical and economic issues generally prevent their overlap [6].[7] For clean water pumps, some positive displacement pumps, such as piston pumps, can be used instead of rotodynamic pumps, but they are more expensive and typically have higher maintenance costs, making users more likely to choose rotodynamic pumps. On the other hand, for high head (pressure) applications, rotodynamic pumps have increased cost and less reliability, making users more likely to choose positive displacement pumps.

Item 1-6 DOE seeks comment on its proposal to consider standards for rotodynamic pumps and not positive displacement pumps. In particular, DOE requests comment on the extent of the overlap between rotodynamic and positive displacement pumps and whether there are certain categories of rotodynamic pumps (pump types and ranges of flow and specific speed) for which positive displacement pumps could be a direct replacement.

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[6] DOE notes that Executive Order 13609 of May 1, 2012 promotes international regulatory cooperation. 77 FR 26413. http://www.gpo.gov/fdsys/pkg/FR-2012-05-04/pdf/2012-10968.pdf.

[7] The analysis will consider switching between rotodynamic and positive displacement pumps.

1.2.1.3 Pump Equipment Categories

An overview of pump equipment categories is presented in Table 1.1, with a preliminary indication of the categories for which DOE is considering energy conservation standards, as well as the categories considered by the stakeholders based on EU coverage, for comparison. DOE's proposed pump categories constitute up to 70 percent of commercial and industrial pump (including rotodynamic and positive displacement) energy use [6], as well as approximately 40 percent of industrial pump sales by unit and 30 percent by value [4]. DOE believes that the pump categories for which DOE is not considering standards in this framework document represent a small market share or are not for clean water use. Section 3.2 on equipment classes provides further discussion of whether each pump category listed warrants a separate equipment class or if a listed pump category requires disaggregation into multiple equipment classes. Table 1.1 identifies the pumps for which DOE is considering energy conservation standards.

Table 1.1 Rotodynamic Clean Water Pump Equipment Overview and Proposed Coverage

Pump Type	Sub-Type	Stages	EU Coverage/Stakeholder Proposal	DOE Coverage Proposal and Terminology
End Suction	Close Coupled	Single	X	End Suction Close Coupled (ESCC)
		Two		
	Own Bearings/ Frame Mounted	Single	X	End Suction Frame Mounted (ESFM)
		Two		
Vertical In-Line		Single	X[*]	In-Line (IL)
		Two		
Axial Split		Single		Double Suction (DS)
		Multi		Axially Split Multi-Stage (AS)
Radial Split		Single		
		Multi	Partial (vertical in-line)[**]	Radially Split Multi-Stage (RS)
Vertical Turbine	Non-Submersible	Any		Vertical Turbine (VT)
	Submersible	Any	Partial (> 1 stage)[***]	Submersible (VT-S)
Axial/Propeller and Mixed Flow		Any		Axial/Propeller and Mixed (A-M)
Regenerative Turbine		Any		
Pitot		Any		

[*] In EU standard, this category is called end suction close coupled inline and therefore presumably only covers close coupled pumps; the stakeholders propose to add flexibly coupled and rigidly coupled pumps to this category.

[**] In EU standard, this is called vertical multistage. Although not clear from the EU standard, the stakeholders have interpreted this to cover only multi-stage in-line casing diffuser pumps.

[***] In EU standard, this is called submersible multistage.

Item 1-7 DOE seeks comment on its proposal to consider standards for pumps not covered in the EU.

Item 1-8 DOE seeks comment on its development of pump equipment categories and whether these categories provide an appropriate basis for developing equipment classes. (See section 3.2.)

Item 1-9 DOE seeks comment on whether standards for any additional pump categories should be considered. In particular, DOE is interested in pump categories that may have significant potential for energy savings.

Item 1-10 DOE seeks comment on the pump types as described by ANSI/HI nomenclature that fall into the equipment categories set forth in Table 1.1. For example, pump type OH1 would be classified as an end suction frame mounted pump. For ANSI/HI pump types that would not fall into the categories in Table 1.1, please provide a specific reason, such as "solids-handling only."

DOE notes that, in the EU, a type of pump known as glandless or wet-running circulators are covered under a separate regulation. While these pumps are manufactured and sold almost exclusively in the EU [7], there is currently a small market for these circulators in the United States. DOE tentatively proposes to cover these wet-running circulators under their relevant equipment categories (most typically end suction close coupled or in-line). DOE notes, however, that standards for circulators (or any pumps) used primarily in residential applications would not be considered in this rulemaking.

Item 1-11 DOE seeks comment on whether wet-running circulator-type pumps should be covered in this rulemaking.

Item 1-12 DOE seeks comment on the market size for wet-running circulators in the United States, including the split between commercial and residential applications in terms of physical size or other features, as well as the potential for growth of the market for circulators in commercial applications.

1.2.2 Parameters for Potential Energy Conservation Standards

The EU standard generally covers pumps up to the practical limits of the equipment, although a few pumps may fall outside of the parameters specified [1]. The parameters are shown in Table 1.2. (Note that the equipment categories listed are not comprehensive of those DOE is proposing for coverage.) DOE has translated the EU limits into the speeds and units used in the United States, as shown in Table 1.3.[8]

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[8] DOE translated these limits for the United States by assuming equivalent pump geometry and increased speed based on frequency (60 hz in the United States versus 50 hz in the EU), and then applying pump affinity laws that show the relationship between changes in speed and changes in head, flow, and power. DOE then converted units from metric to U.S.-based.

Table 1.2 Scope of EU Water Pump Regulation

Pump Category	Defined Scope						
	Speed	Flow at BEP*	Head at BEP	Specific Speed**	Shaft Power	Temp.	Other
End Suction Single-Stage	1,450 rpm[†]	≥ 6 m^3/h[‡]	≤ 90 m	$6 \leq n_s \leq 80$	≤ 150 kW[§]	-10 through +120°C	Pressures up to 16 bar
End Suction Single-Stage	2,900 rpm	≥ 6 m^3/h	≤ 140 m	$6 \leq n_s \leq 80$	≤ 150 kW	-10 through +120°C	Pressures up to 16 bar
Vertical Multi-Stage	2,900 rpm	≤ 100 m^3/h				-10 through +120°C	Pressures up to 25 bar
Submersible Multi-Stage	2,900 rpm					0 through 90°C	Nominal sizes 4" and 6"

* BEP = best efficiency point (the duty point that leads to the maximum efficiency value).

** Specific Speed $n_s = \text{speed} * \overline{\text{Flow at BEP}}/(\text{Head per stage at BEP})^{3/4}$. In the EU regulation, specific speed is calculated from the numerical values for speed in rpm, flow in meters cubed per second, and head in m. Although the EU regulation gives the units rpm or min^{-1} for specific speed, it is not clear how these units were obtained. Specific speed is generally treated as dimensionless

† rpm = revolutions per minute.

‡ m^3/h = cubic meters per hour.

§ kW = kilowatts.

Table 1.3 EU Scope Translated for the United States

Pump Category	Defined Scope (Based on Affinity Laws)						
	Speed	Flow at BEP	Head at BEP	Specific Speed**	Shaft Power	Temp.	Other
End Suction Single-Stage	1,750 rpm	≥ 32 gpm*	≤ 430 feet	$312 \leq N_s \leq 4{,}160$	≤ 353 HP[†]	14 through +248°F	Pressures up to 232 psi absolute
End Suction Single-Stage	3,500 rpm	≥ 32 gpm	≤ 669 feet	$312 \leq N_s \leq 4{,}160$	≤ 353 HP	14 through +248°F	Pressures up to 232 psi absolute
Vertical Multi-Stage	3,500 rpm	≤ 531 gpm				14 through +248°F	Pressures up to 363 psi absolute
Submersible Multi-Stage	3,500 rpm					32 through 194°F	Nominal sizes 4" and 6"

* gpm = gallons per minute.

** Specific Speed (N_s) is calculated using the same equation shown in the previous table using the numerical values for speed in rpm, flow in gpm, and head in feet. N_s is treated as dimensionless.

† HP = horsepower.

Stakeholders have proposed that DOE consider standards for the following pumps in this rulemaking:

- 25 gpm and greater;
- 295 feet of head maximum;
- 1-200 horsepower (HP); and
- temperature range from -10 °C through +120 °C.

According to stakeholders, this approach is meant to generally align with the EU scope and is designed to focus on off-the-shelf pumps and to exempt pumps with low flow and fractional horsepower that have little opportunity for efficiency improvement and energy savings. DOE estimates that these parameters would exclude the percentages of pumps, by model availability and shipment, shown in Table 1.4.

Table 1.4 Stakeholder Proposed Scope Exclusions

Pump Category	**Percent Excluded**	
	Model Availability*	**Shipments (Units)****
End Suction Close Coupled (ESCC)	43%	71%
End Suction Frame Mounted (ESFM)	41%	34%
In-Line (IL)	43%	47%
Double Suction (DS)	58%	32%
Axially Split Multi-Stage (AS)	80%	86%
Radially Split Multi-Stage (RS)	87%	49%
Vertical Turbine (VT)	49%	43%
Submersible (VT-S)	54%	42%
Axial/Propeller and Mixed (A-M)	36%	40%
Total	**48%**	**68%**

*Based on more than 27,000 clean water pump models extracted from PUMP-FLO™ Desktop, a pump selection tool from Engineered Software.
**DOE estimates.

Many multi-stage pump models would be included in the pump percentages listed in Table 1.4 as a result of the maximum proposed head (295 feet), because the purpose of multi-stage pumps is to provide increased head. Vertical turbine pumps and radially split multi-stage pumps, however, are generally cellular in nature; in other words, all stage versions of a given pump are based on the same bowl, and identical bowls are stacked together to create multi-stage versions. Therefore, if DOE were to set standards for this type of pump, improving efficiency for models with less than 295 feet of head would also result in efficiency improvements for models with higher than 295 feet of head. Furthermore, for these pumps, DOE may consider testing on basic models with a certain number of stages (see section 1.4.5), which would make a maximum head limit unnecessary.

Under the stakeholders' approach, standards would also not be considered for many pumps in certain categories as a result of the maximum temperature (+120 °C). These categories include end suction close coupled (ESCC), double suction (DS), and axially split multi-stage (AS).

If DOE does not consider standards for ANSI pumps, however, many of which have high temperature ranges, the percent of clean water pumps excluded by a maximum temperature limit would be much lower. (See comment Item 1-4).

In this framework document, DOE is not considering adopting coverage parameters except possibly to exempt certain pumps from standards for specific reasons. For example, because this rulemaking focuses on commercial and industrial pumps, DOE may not consider standards for pumps used primarily in residential applications.

Item 1-13 DOE requests comment on which parameters, if any, should be added to this rulemaking. For each parameter proposed, please include the rationale and the type of pump that the parameter is designed to exclude from standards. Comments may address those translated from the EU or those proposed by stakeholders, but do not have to be limited to those proposals. DOE especially seeks comments on parameters that should be added to exclude pumps used primarily in residential applications. DOE also seeks comment on whether, if using power as a coverage parameter, hydraulic power would be more appropriate than shaft power.

Item 1-14 DOE requests comments on the estimates of pumps that would be excluded based on the stakeholders' proposed parameters.

The EU regulation and the stakeholder proposal also exclude self-priming pumps and pumps designed only for fire-fighting applications. Self-priming pumps are used primarily for the wastewater industry and are thought to be cost prohibitive in applications where they are not necessary. Fire-fighting pumps are excluded because of their low hours of use, but they are often identical to clean water pumps and so would likely meet the applicable standards. If these pumps are likely to be purchased and used for applications other than their intended ones, however, they may warrant coverage.

The term self-priming generally refers to pumps mounted above liquid level that can, after initial priming, evacuate gases from the suction line and lift fluid to the pump inlet without intervention and without requiring a foot check valve. However, some HI standards refer to pumps with the wet end immersed in water, such as vertical turbine pumps, as self-priming, and the EU definition[9] may also consider this type of pump as self-priming. For the purposes of this framework document, DOE intends to adopt a narrower definition of self-priming that would not include vertical turbine pumps, on the basis that vertical turbine pumps are not mounted above liquid level, and thus do not feature the design characteristics typical of true self-priming pumps.

Item 1-15 DOE requests comment on the technical features and applications for fire-fighting pumps and self-priming pumps that would allow it to determine whether these pumps should be covered.

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[9] "A water pump that moves clean water and which can start and/or operate also when only partly filled with water."

1.2.3 Pumping System

There may be greater potential for energy savings if the energy conservation standards addressed pumps as a system of components. Pump systems are subject to a variety of inefficiencies, and those inherent in the pump are often among the smallest. As a result, addressing other system inefficiencies[10] in any DOE regulations could significantly increase energy savings. The EU has been exploring an approach for equipment sold in a package with a motor and control, and the stakeholders have also agreed to explore the issues associated with setting standards for pump systems. The main goal of such an approach is to capture the benefits of variable speed drives (VSDs). VSDs are control devices that can be used to improve equipment performance under variable loads. The savings potential is highly dependent on (a) how much time the system requires operation at a reduced load (*i.e.,* flow less than full flow); and (b) the means, if any, used to adjust pumping system operation during these times. For example, systems that use throttling valves to reduce flow while maintaining pump speed for many hours per year have the potential to significantly reduce annual energy use by using VSDs to instead reduce flow by reducing the pump speed.

It is important to note, however, that VSDs used under constant load operation conditions may degrade efficiency because of the electric losses in the VSD during full load operation. In addition, the savings also depend on the pressure and flow characteristics of the system. If the system head requirement includes a large percentage of constant head (i.e. static head)—for instance, to lift water from a low location to a high location—the potential for energy savings through use of VSDs is significantly less. For these reasons, VSDs are best applied to pumps used primarily in applications with variable load and relatively low static head. However, the same pump equipment is often installed with a VSD in some cases and without it in others. In fact, DOE is not aware of any specific pump type that is always used in an application that would benefit from a VSD. As a result, DOE would consider the impacts of VSDs in various applications in determining whether to establish energy conservation standards that could increase the use of VSDs in any pump equipment categories.

Item 1-16 DOE requests data on how pumps are sold by pump manufacturers. Specifically DOE requests data on market share of pumps 1) sold by themselves, 2) sold attached to or integrated with motors only, 3) sold attached to or integrated with both motors and VSDs, 4) sold physically separate from but priced together with a motor only, or 5) sold physically separate from but priced together with both a motor and VSD. DOE seeks these data by size, equipment category (see section 3.2), and application.

Item 1-17 DOE requests data and information on whether pumps are more often combined with motors, VSDs, or both by the pump manufacturer or by distributors.

Item 1-18 DOE requests information on how often and in what circumstances the intended application of the pump is known when the pump is sold.

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[10] These other inefficiencies include mismatch of pump to system requirements, use of throttling valves and dampers to control flow, running at constant load all the time when load is or could be variable, and use of inefficient motors and inefficient motor drives.

Item 1-19 DOE understands that VSDs are not very effective without system feedback. DOE seeks comment on the need for considering feedback in any extended product-type definition for pumps.

DOE is considering the following options for regulation depending on how pumps are defined and sold:

1. Defining and establishing standards for the pump exclusive of the motor, except possibly for submersible pumps. This option follows the current EU approach for clean water pumps.

2. Defining and establishing standards for the pump inclusive of the motor and controls, if the pump is sold with them. Using this approach, each pump equipment class would be sub-divided into two categories: (1) without VSD (pump is sold with or without motor) and (2) with VSD (VSD included only if the pump is sold with a motor).[11]

3. Defining and establishing standards for the pump inclusive of the motor, if the pump is sold with a motor[12], and considering the VSD as a design option to improve the efficiency of pumps sold with motors. Each pump equipment class could be divided into two further categories: (1) without motor (or VSD) and (2) with motor (with or without VSD).

Based on DOE's preliminary research, option 1 would be the simplest approach. Option 2 has potential to capture additional energy savings because it directly addresses the use of more efficient VSD and motor pairs than might be sold in the absence of a standard. Option 3 may increase the potential to capture savings associated with system inefficiencies, as a metric could be developed to demonstrate energy savings associated with reducing flow using a VSD to address operation when full load is not required, rather than by less efficient means, such as using throttling valves to reduce flow. DOE notes that in options 2 and 3, the same pump could be placed into two different equipment classes, one for the pump alone and the other for the pump sold with the motor or motor and controls. Each equipment class would be subject to a separate energy conservation standard.

DOE realizes that pump manufacturers cannot control if or how a VSD is used in the field. In addition, a standard that requires or encourages the use of VSDs could result in the presence of VSDs in applications for which they are not suited, such as constant loads with correctly sized pumps or variable loads with high static head. To determine whether selling more pumps with VSDs (the possible result of option 3) or selling more efficient VSD/motor pairs (option 2) would actually save energy in the field, DOE will conduct analyses of pump and VSD usage across the full spectrum of pump applications and baseline conditions (including throttling valves, bypass valves, on/off cycling, and constant full speed operation).

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[11] As noted previously, most pump motors (85 percent to 90 percent) are already subject to energy conservation standards. One of the key exceptions is submersible motors, which are used with submersible pumps.

[12] The presence of a motor can be used as a feature to differentiate equipment classes because the pump manufacturer is likely to make an informed decision about the appropriate motor to pair with a given pump, which offers utility to the consumer.

Item 1-20 DOE requests comment on the benefits and drawbacks of the options presented above. For options 2 and 3, DOE seeks comment on whether these options could increase the beneficial use of VSDs in the field, and whether these options could result in the use of a VSD in an application for which it is not suited.

Item 1-21 DOE seeks comment on the market share of pumps by category that would be used in applications that would benefit from VSDs, as well as those where use of a VSD could result in increased energy use.

DOE notes that not all pumps are driven by electric motors; some pumps may be driven by natural gas or diesel engines or steam turbines. These pumps may represent 10% or less of the pumps that DOE is currently considering regulating through efficiency standards. Because some pumps can be used with both motors and engines, DOE is considering in this framework document setting standards for pumps without regard to how they are driven. Any pump sold with an engine or for use with an engine (as opposed to an electric motor) would likely be regulated as a pump sold without a motor if DOE defines pumps to include the motor or motor and controls.

Item 1-22 DOE seeks comment on the market share and applications of pumps by category driven by equipment other than an electric motor.

1.3 Equipment Definitions

In this rulemaking, DOE is considering a definition for pumps (commercial and industrial), definitions for specific types of pumps, and a definition of 'clean water'. In the June 2011 RFI, DOE requested comment on definitions for 'rotodynamic pumps', 'centrifugal (radial) pumps', 'mixed flow pumps', 'axial flow pumps', and 'positive displacement pumps'. DOE also reviewed the definitions in the EU regulation for water pumps [1]. DOE has based the following definitions on those in the EU regulation but has not specified the parameters discussed in section Item 1-11 and has made other changes for clarification. In addition, DOE has proposed definitions for additional equipment coverage beyond that in the EU regulation. DOE may add any parameters determined appropriate for this rulemaking to the pump definitions. The proposed definitions follow.

'***Pump***' is a device that moves clean water by physical or mechanical action.

'***Rotodynamic water pump***' means a pump that moves clean water by means of hydrodynamic forces, excluding regenerative turbine pumps.

'***End suction water pump***' means a single-stage rotodynamic water pump in which the liquid enters the pump from the end, opposite the pump's shaft-end and parallel with the shaft, and the discharge is at a right angle from the shaft.

'***End suction frame mounted water pump***' is an end suction rotodynamic water pump with its own bearings; such a pump does not rely on the motor bearings to support the impeller.

‘***End suction close coupled water pump***’ is an end suction rotodynamic water pump in which the motor shaft is extended to become also the pump shaft.

‘***In-line water pump***’ means a single-stage rotodynamic water pump in which the water inlet of the pump is on the same axis as the water outlet of the pump; such pumps are generally installed with the shaft oriented vertically and the motor on top.

‘Radially split multi-stage water pump’ means a rotodynamic water pump with two or more stages in a radially split case. Flow proceeds from the inlet through the stages in series, with each stage increasing the total head. The flow rate is the same through each stage.

‘***Submersible water pump***’ means a rotodynamic water pump with one or more stages designed to be operated in a borehole with the motor fully submerged in the pumped water; such pumps are generally vertical turbine pumps with submersible motors mounted to the bottom.

*‘**Double suction water pump***’ means an axially split single-stage rotodynamic water pump with two inlets.

‘Axially split multi-stage water pump’ means a rotodynamic water pump with two or more stages in an axially split case that is generally oriented horizontally.

‘Vertical turbine water pump (non-submersible)’ means a rotodynamic water pump in which liquid enters the lower end through the suction bell and then passes through one or more stages with impellers and diffuser cases called bowls; these pumps are narrow in diameter as a result of their origin as deep-well pumps, and the diffuser bowls are in-line with the impellers rather than outside them; above the column section, the pump supports a vertical motor located above the pumped water.

‘Axial/propeller and mixed flow water pump’ means a rotodynamic water pump with an impeller(s) that develops head (pressure) through axial or close to axial forces or a mix of axial and radial forces, with the characteristic of relatively high rotational speed and flow relative to head or intermediate flow and head.[13]

Item 1-23 DOE requests comment on the suggested definitions for pumps.

Item 1-24 DOE requests input on whether the definitions proposed by DOE are sufficient to allow manufacturers to determine whether their pumps are covered, and in which pump category their equipment falls.

Item 1-25 DOE requests comment on what minimum specific speed should define the axial/propeller and mixed flow water pump.

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[13] There is no definite demarcation that separates mixed or axial flow pumps from the more common radial flow pumps. However, ranges of specific speed can be used.

DOE is also considering the EU definition for 'clean water':

> '***Clean water***' means water with a maximum non-absorbent free solid content of 0.25 kg/m^3, and with a maximum dissolved solid content of 50 kg/m^3, provided that the total gas content of the water does not exceed the saturation volume. Any additives that are needed to avoid water freezing down to -10°C shall not be taken into account.[14]

Item 1-26 DOE requests comment on the definition of 'clean water'. DOE specifically requests input on the translation of wording and units to those typically used in the United States, such as parts per million limits for suspended and dissolved solids. DOE also seeks comment on the appropriateness of the proposed limits. DOE requests clarification on whether mixtures including water with freezing points above -10°C should be considered clean water for the purposes of this definition and rulemaking.

Item 1-27 DOE requests comment on whether maximum solids diameter, which is a parameter provided with many pump curves, could be used in the definition of 'clean water'.

1.4 Efficiency Metrics and Implementation Methods

To establish a metric[15] to determine efficiency for this rulemaking, DOE reviewed the metrics and implementation methods used in other regulatory or voluntary programs.

1.4.1 Pump Efficiency

Pump efficiency is the ratio of hydraulic power (the product of flow, density, gravity, and head) to shaft input power. Pump efficiency does not take motor efficiency into account.

1.4.1.1 European Union – Clean Water Pumps

The metric used in the EU regulation for water pumps used in commercial buildings, drinking water pumping, the food industry, and agriculture is the pump efficiency [1]. The EU has requirements at three different points along the pump pressure/flow curve when operating at the pump's rated speed: full load (*i.e.,* at Best Efficiency Point (BEP)), part load (*i.e.,* at 75 percent of flow at BEP), and overload (*i.e.*, at 110 percent of flow at BEP). The EU standard would set a required efficiency for BEP, and the minimum pump efficiency at part load, and overload would be set at the required BEP efficiency multiplied by a factor equal to 0.947 and 0.985, respectively. A failure at one or more points would mean the pump did not meet the standard. This approach accounts for the fact that pumps do not always operate at BEP and has the potential to increase pump efficiency over a wider range of operating conditions.

For minimum pump efficiency levels, the EU is using an equation based on pump type, rotating speed, flow, and specific speed (all of which are parameters that affect efficiency):

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[14] The EU definition of 'clean cold water' for testing purposes differs from this definition of "clean water" and includes viscosity, density, and temperature limits.

[15] A metric is a standard of measurement, or the parameter DOE will use to determine if a pump meets an energy conservation standard.

$$(\eta_{BEP})_{\min requ} = 88.59x + 13.46y - 11.48x^2 - 0.85y^2 - 0.38xy - C_{Pump\ Type,rpm}$$

Where,
$x = \ln(n_s)$; $y = \ln(Q)$; ln= natural logarithm; Q = flow in [m^3/h]; n_s= specific speed; C= value found in Table 1.5. [1]

The EU equation, which describes a three-dimensional surface, was defined using data from a 1998 investigation [7]. The equation is intended to represent pumps that have the same stringency of achievable efficiency across all different parts of the surface. The EU sets efficiency standards based on desired percentages of the market to cut-off, and they refer to these as minimum efficiency indexes (MEIs). By changing the constant, C, the surface can be raised and lowered until the desired percentage of market to cut-off is achieved for a particular pump equipment class (*i.e.,*. the percentage of pumps desired to be impacted by the standard is lying below the surface). Table 1.5 shows sample values of C. The EU analyzed potential standards from 5% cut-off to 80% [9], and the final standard has phased implementation of 10% and 40% levels [1].

Table 1.5 Sample C Values for EU Minimum Pump Efficiency Equation

	C value	
Equipment Class	**MEI= 10%**	**MEI=40%**
End Suction Own Bearings, 1450 rpm	132.58	128.07
End Suction Own Bearings, 2900 rpm	135.60	130.27
End Suction Close Coupled, 1450 rpm	132.74	128.46
End Suction Close Coupled, 2900 rpm	135.93	130.77

The EU standard and testing is based on pumps with a full impeller.[16] For vertical multi-stage water pumps, compliance with the standard is based on testing a product with three stages, rather than all stage versions of the same basic pump. For submersible multi-stage water pumps, compliance is based on testing a product with nine stages.

The stakeholders have proposed that DOE use the EU metric and approach in considering standards for clean water pumps.

1.4.1.2 Hydraulic Institute (United States)

HI 20.3-2010 (Rotodynamic [Centrifugal and Vertical] Pump Efficiency Prediction) provides information and figures to predict pump efficiency at a given flow and specific speed for industrial-class rotodynamic pumps [11]. Descriptions of these figures (provided in both metric and English units) follow:

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[16] 'Impeller' means the rotating component of a rotodynamic pump that transfers energy to the water. 'Full impeller' means the impeller with the maximum diameter for which performance characteristics are given for a pump size in the catalogues of a water pump manufacturer. "

- Figures 20.3a and b provide efficiency versus flow rate curves (at optimum specific speed) for 10 different pump categories (eight curves, as some pump categories share a curve).
- Figures 20.3c and d provide efficiency corrections (in efficiency points) based on specific speed (two curves; one represents nine pump categories).
- Using Figures 20.3a and b and c and d in combination results in a generally attainable efficiency for a given pump category at a given flow and specific speed.
- Figures 20.3e and f also provide potential deviation (minimum and maximum curves) from normally attainable efficiency by flow, allowing the user to determine the range of available pump efficiencies for a given pump type, flow, and specific speed (when used in sequence with Figures a and b and Figures c and d).

Figures 20.3g and h and Figures 20.3i and j provide additional information on efficiency increases from improved surface finishes and efficiency decreases due to increased wear ring clearances, respectively, but these are designed to help users determine the benefit of making improvements to existing, in-use pumps.

1.4.1.3 Mexico – Vertical Turbine Pumps

Mexico regulates vertical turbine pumps with external vertical electric motors for pumping clean water for irrigation, municipal supply, or industrial supply [8]. For these products, there are minimum pump efficiency levels at BEP for 16 equipment classes based on nominal bowl diameter and flow ranges. Further adjustments for efficiency are also specified for pumps with fewer stages than specified based on catalog curves.

1.4.1.4 South Korea

South Korea's voluntary certification program is based on pump efficiency, according to an EU report [9]. Flow at BEP must be within a specified range for each specified discharge bore size. Efficiency at BEP must exceed a specified point defined by a plot of efficiency versus flow. The efficiency at all flows within the specified range of flow must exceed a point on a separate plot of efficiency versus flow, which is approximately 12 efficiency points below efficiency at BEP. This is designed to encourage broad efficiency curves. This method does not take into account specific speed or head, and target efficiencies do not take into account number of stages.

1.4.1.5 China

China's efficiency standards are based on pump efficiency at BEP [10]. China uses several divisions of products when setting minimum efficiency values. There are three main pump categories, and, within each of these categories, additional groupings are based on flow ranges and specific speed ranges. The same specific speed correction is used for all pump categories.

1.4.1.6 European Union – Clean Water Pump Selection Guide

The EU has a non-regulatory selection guide for single-stage centrifugal clean water pumps [12]. As in the EU regulation for water pumps, this guide is based on the relationship between pump efficiency, flow, and specific speed. Developers wanted to avoid explaining specific speed to pump buyers [9], however, so for each pump type and speed, they produced a single figure showing efficiency versus flow rate at optimum specific speed with efficiency correction curves for various head levels superimposed. The user can look at a single figure, find optimum pump efficiency at a certain flow, and then subtract efficiency points for a given head from the head correction curves to find out what level of efficiency to expect from a given type and size of pump.

1.4.2 Overall (Wire-to-Water) Efficiency

Another metric used for pump regulatory programs is overall, or wire-to-water, efficiency. Overall efficiency is the ratio of hydraulic power to the electric power input at the motor and/or the VSD driving the motor.

1.4.2.1 Mexico – Submersible Pumps

The Mexico standard for submersible deep well clean water three-phase motor pumps is based on an overall efficiency metric [13]. The minimum overall efficiency a pump-motor unit must meet is based on the multiplication of a minimum pump efficiency level (based on nine ranges of pump capacity) and a minimum motor efficiency level (based on ten ranges of motor size). This effectively results in different minimum overall efficiency levels for 90 equipment classes.

1.4.3 Other

1.4.3.1 European Union – Circulators

The EU regulation for circulators uses an energy efficiency index (EEI), which is the ratio of the average hydraulic power for a pump (at four different flows) to a reference power derived from the relationship between maximum hydraulic power and maximum power consumption for the majority of circulators on the market [14].

1.4.3.2 Hydraulic Institute – Vertically Suspended Pumps

ANSI/HI 14.6-2011 (Rotodynamic Pumps for Hydraulic Performance Tests) specifies that the performance for vertically suspended pumps (which includes vertical turbines) should be based on bowl performance [15]. This is because vertically suspended pumps may be sold with any number of stages, all based on a given bowl. Manufacturers would test the bowl for performance, as losses for a specific pump configuration would not be known until finalized. Bowl efficiency is the ratio of bowl hydraulic power output to bowl shaft or electric power input.

1.4.4 DOE Efficiency Metric Considerations

1.4.4.1 Overview

As discussed in section 1.2.3, DOE is considering whether to define and establish standards for pumps, pumps inclusive of the motor, or pumps inclusive of the motor and VSD. Table 1.6 summarizes the metric DOE is considering for each regulatory option. The subsequent section discusses the metrics and reasons for their selection.

Table 1.6 Tentative Proposed Metrics for Pump Regulation Options

Regulatory Option		Equipment Class Set	Metric
1	Pumps	N/A	Pump efficiency at three points
2	Pumps inclusive of motor and VSD	Pumps Without VSD (with or without motor)	Pump efficiency at three points
		Pumps With VSD	Overall efficiency at three points
3	Pumps inclusive of motor, with VSD as a design option for all pumps sold with motors	Pumps Without Motor	Pump efficiency at three points
		Pumps With Motor (with or without VSD)	Potentially based on motor/VSD input power at multiple load points*

*DOE may also consider the use of pump efficiency as an additional metric or labeling requirement.

1.4.4.2 Option 1

If DOE defines and regulates the pump exclusive of the motor and VSD (option 1 in section 1.2.3), DOE is considering following the EU's clean water pump approach based on pump efficiency at BEP (at rated speed), part-load (75% of BEP flow), and overload (110% of BEP flow), where the pump must meet all three points to meet the standard. As mentioned previously, this approach has the potential to increase pump efficiency over a wide range of operating conditions. However, for submersible pumps, for which the submersible motor is an integral part of the pump, accurate determination of pump efficiency may be difficult as losses must be accounted for and distributed between the motor (seal losses) and the pump (losses internal to the pump wet end, losses caused by using pumped liquid to cool the driver, etc.). As a result, DOE may consider a metric of overall (wire-to-water) efficiency (within the framework of the EU standard) for submersible pumps. Alternatively, DOE may consider a metric of bowl efficiency for vertically suspended pumps including vertical turbines and submersibles, as DOE understands that this is common testing practice for manufacturers.

Item 1-28 DOE requests comment on its proposal to follow the EU approach using pump efficiency if pumps are defined without the motor or controls. DOE is especially interested in whether a pump should have to meet a standard at multiple load points, or if a weighted average metric should be developed.

Item 1-29 DOE requests comment on the selection of 75% BEP flow as the part-load point and 110% as the overload point and whether these are the most appropriate points to encourage broad pump efficiency curves.

Item 1-30 DOE requests comment on whether the use of an overall efficiency metric for submersible pumps would cause problems for manufacturers, as the EU metric is pump efficiency.

Item 1-31 DOE requests comment on whether the metric for vertically suspended pumps should be bowl efficiency rather than pump efficiency.

1.4.4.3 Option 2

If DOE defines and regulates pumps inclusive of the motor and VSD if sold together (option 2 in section 1.2.3), DOE would follow the same metric approach discussed for regulation option 1 for equipment classes for pumps sold without VSDs. For equipment classes for pumps sold with VSDs, DOE would identify a metric that can be used to consider efficiency levels that require the use of more efficient VSDs; such a metric does not need to compare pumps with VSDs to pumps without VSDs, because pumps without VSDs (with or without motors) would be in a separate set of equipment classes. For extended products including both motors and VSDs if sold together, DOE is considering a metric of overall efficiency, measured as the ratio of hydraulic power to the electric power input at the VSD. (This metric can also be thought of as the product of pump efficiency, motor efficiency, and VSD efficiency.) DOE is considering capturing overall efficiency at BEP, part-load (75% of BEP flow), and overload (110% of BEP flow) for this metric as well. The pump, motor, and VSD must be tested together because VSDs are not regulated separately (and thus there is no verified source of VSD efficiencies), motors are regulated only at full-load, and VSDs and motors in combination do not necessarily operate with the efficiency that would be calculated by multiplying their individual tested efficiencies together.

Item 1-32 DOE requests comment on its proposal to adapt the EU standard metric to overall efficiency for pumps sold with both motors and VSDs. DOE is also interested in whether additional test points should be added below 75% of BEP flow to address more of the operating range of pumps with VSDs.

1.4.4.4 Option 3

If DOE decides to define and regulate pumps inclusive of the motor if sold together and include VSD as a design option (option 3 in section 1.2.3), DOE would follow the same metric approach discussed for regulation option 1 for equipment classes for pumps sold without motors. For equipment classes sold with motors, DOE would identify a metric that can capture the impacts on energy efficiency associated with the use of a VSD in comparison to a pump with a motor but without a VSD. DOE could then consider efficiency levels that require VSDs and high-efficiency VSDs.

VSDs create two main energy-related benefits compared to throttling (either to better match the pump to a constant load or to match different loads at different times). First is the ability to reduce power when operating at flows lower than full flow[17]; pumps roughly follow affinity laws, and in the "cube law", pumps running at 75% speed require approximately 42% power, for example, depending on a variety of parameters, including the system in which the pump operates. Figure 1.1 demonstrates this effect, as the power required at 75% flow using

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[17] This benefit may be realized in variable load systems when flows less than the maximum flow are required. It may also be realized in constant load systems with oversized pumps, when a VSD is used to reduce speed and flow to the system requirements; however, it would use more power in constant load systems with correctly sized pumps.

speed reduction is much less than the power required at 75% flow using throttling. Note that 75% is just an example; the "cube law" can be used with different speed reductions as well. Second, when reducing flow by shifting the pump performance curve using speed control, pump efficiency is roughly maintained relative to BEP. When reducing flow by throttling (and shifting the system curve), pump efficiency degrades. Figure 1.1 also demonstrates this effect, as pump efficiency at Point B (throttling) is lower than pump efficiency at Point C (speed reduction). Figure 1.1 shows both of these benefits for a friction-only system (*i.e.,* a system with no static head), in which VSD benefits are greatest. Systems with high static head will have lower power savings and will also have lower efficiency at reduced flows. If relatively high heads must be maintained at low flows, very little speed reduction may be possible.

Use of a VSD introduces losses into the system, which can be seen in overall or wire-to-water efficiency. At all flows, a pump with VSD will have lower overall efficiency than a pump without VSD. Furthermore, while motor efficiency does not degrade significantly with speed reductions up to 50% or more, the efficiency of a VSD degrades more significantly. As a result, overall efficiency at 75% flow using a VSD is less than overall efficiency at 100% BEP flow and may be less than overall efficiency at 75% flow achieved through throttling, depending on a variety of parameters including the pump efficiency curve. However, at reduced flows, this efficiency loss, combined with the significantly reduced power requirements of a VSD, means that the power drawn by the motor and VSD will still be less than the power drawn for a throttled situation. Table 1.7 shows an example of the effect of drive efficiency on overall efficiency, as well as the resulting motor/drive input power requirements.

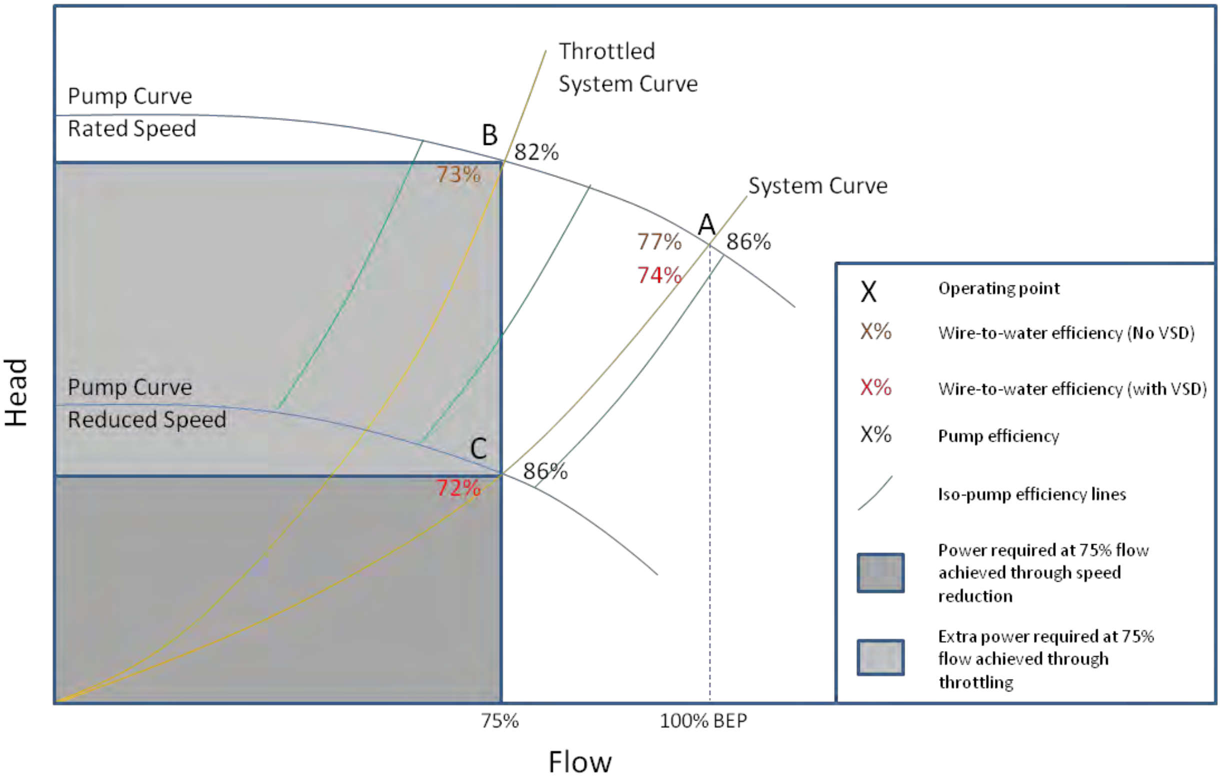

Figure 1.1 Flow Reduction from Throttling and Use of VSD

Table 1.7 Example Pump Parameter Comparison With and Without VSD

		Without VSD		With VSD	
		Rated Speed, 100% BEP Flow	Rated Speed, 75% BEP Flow (Throttled)	Rated Speed, 100% BEP Flow	Reduced Speed, 75% BEP Flow
Operation Conditions	Flow (gpm)	120	90	120	90
	Head (feet)	300	330	300	169
	Speed (rpm)	3550	3550	3550	2663
Efficiencies	Pump Efficiency	86%	82%	86%	86%
	Motor Efficiency	89%	89%	89%	89%
	VSD Efficiency	N/A	N/A	97%	94%
	Combined Motor/VSD Efficiency	N/A	N/A	86%	84%
	Overall Efficiency	77%	73%	74%	72%
Power	Water (Hydraulic) HP	9.1	7.5	9.1	3.8
	Pump Shaft Input Power (HP)	10.6	9.1	10.6	4.5
	Motor/ VSD Input Power (HP)	11.9	10.3	12.2	5.3
Potential Metrics	Motor/VSD Input Power Per Unit Operating Flow (HP/ gpm)	0.099	0.114	0.102	0.059
	Ratio motor/VSD input power at given condition to motor/VSD input power at full speed, 100% flow, no VSD condition	1.00	0.87	1.03	0.45

DOE would consider metrics other than pump and overall efficiency to capture the energy efficiency impacts of VSDs for pumps sold with motors. These metrics may need to be based on motor/control input power, such as the input power requirement per unit flow[18] or the ratio of input power at part-load to input power at full-load measured or calculated without VSD, rather than efficiency metrics for the pump, pump/motor, or pump/motor/VSD combination only. Table 1.7 shows examples of these metrics. Such metrics show both the power-saving benefits of VSDs and the losses associated with the presence of a VSD. DOE is interested in suggestions for metrics that would achieve the stated goals for this approach.

Item 1-33 DOE requests comment on the appropriate metric to capture the energy efficiency impacts of VSDs. DOE is interested in whether test points at BEP, 75% BEP flow, and 110% BEP flow are appropriate for this metric and whether additional test points should be added below 75% BEP flow to address more of the operating range of pumps with VSDs. DOE is also interested in whether pumps should be required to meet minimum levels at multiple points or if a weighted average metric should be developed.

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[18] Although a power per flow requirement could potentially be seen to penalize high-pressure pumps, a standard could be based on specific speed, which would take into account head needs.

1.4.4.5 Additional Considerations

For the overload condition (110% of BEP flow), DOE is considering whether for both regulation options 2 and 3, overspeeding should be used to achieve the overload test point for the metrics designed to capture the benefits of VSDs. This may not be a realistic way to provide an indication of how the pump performs in the field, as most pumps are likely oversized and could be operated at 110% of BEP flow without overspeeding. However, some systems could be set up to use overspeeding on occasion to meet especially large loads instead of oversizing the pump for its general duty.

Item 1-34 DOE requests comment on whether the metric for regulatory option 2 and 3 should include an overload test point based on overspeeding.

As mentioned previously, if DOE defines pumps inclusive of the motor or motor and VSD, DOE would likely have two sets of equipment classes for regulatory options 2 and 3. (Regulatory option 1, where pumps are defined exclusive of the motor and controls, would have only one set of equipment classes.) For regulatory option 2, there would be one set for pumps sold without a VSD and one set for pumps sold with a VSD. For regulatory option 3, there would be one set for pumps sold without a motor and one set for pumps sold with a motor. DOE is exploring the options for metric alignment for these different cases, and the metrics for use within each option are summarized in Table 1.8.

- *Separate metrics:* DOE would use metrics that differ by equipment class set within each regulatory option. For example, a pump sold without a motor or drive would use a pump efficiency metric that considers only pump losses, while a pump sold with a motor and drive would use an overall efficiency metric that also considers losses associated with motor and control inefficiencies. Although efficiencies would not be comparable across equipment class sets (i.e. pump efficiency would generally be higher than overall efficiency because it includes only pump losses), this would allow for an appropriate metric to be used to evaluate energy saving potential for the different equipment.

- *Same metrics:* DOE would use the same metric for both sets of equipment classes in a given regulatory option. The test procedure would specify nominal motor and/or VSD efficiency to be incorporated into the performance metric for pumps sold without one or both items. This option could enable the test results for all pumps to be directly comparable regardless of the equipment with which they are sold. DOE notes, however, the motor or VSD used in the field may have different efficiency characteristics than those selected for testing.

- *Multiple metrics for equipment sold with a VSD (or with the motor where a VSD is a technology option to improve efficiency).* DOE is analyzing whether the equipment class set that addresses VSDs could have two metrics. In the alternative, DOE is analyzing whether one of the metrics could be used as a labeling requirement. This approach would allow comparison across all pumps using the common metric of pump efficiency, no matter how the pumps are sold, and also would account for the motor or VSD actually used with the pump.

Table 1.8 Metric Alignment Options

Regulatory Option		Equipment Class Set	Metric Alignment Options		
			Separate	**Same**	**Multiple**
2	Pumps inclusive of motor and VSD	Pumps Without VSD (with or without motor)	Pump Efficiency	Overall Efficiency (standardized motor and VSD)	Pump Efficiency
		Pumps With VSD	Overall Efficiency	Overall Efficiency	Pump Efficiency and Overall Efficiency
3	Pumps inclusive of motor, with VSD as a design option for all pumps sold with motors	Pumps Without Motor	Pump Efficiency	Motor/VSD Input Power Based (standardized motor)	Pump Efficiency
		Pumps With Motor (with or without VSD)	Motor/VSD Input Power Based	Motor/VSD Input Power Based	Pump Efficiency and Motor/VSD Input Power Based Metric

DOE notes that the options for metric alignment may impact manufacturer burden. For pumps sold both with and without motors or with and without VSDs, the same pump may be included in two different equipment classes, one for the pump alone and one for the pump with the motor or motor and VSD. Each of these equipment classes would be subject to a different standard. The same test stand, however, could be used in both cases, and some metrics or metric alignment options may simply require additional measurements or calculations. For example, in regulatory option 2, the separate alignment option would require reporting pump efficiency for a pump sold without a VSD and overall efficiency for a pump sold with a VSD. The manufacturer would measure hydraulic power in each case, but for pumps without VSD they would also measure shaft input power, while for pumps with VSDs, they would measure electric input power to the VSD. For the same metric alignment option, the same testing would be required, but for pumps without VSD, the pump efficiency would be multiplied by a standard motor and VSD efficiency to arrive at the overall efficiency (in other words, standardized efficiencies could be employed rather than requiring testing with standardized motors and VSDs).

Item 1-35 DOE recognizes that the same pump may in some cases be sold alone or may be sold in conjunction with a motor or motor/control package. DOE seeks comment on any issues that may result from having different metrics for pumps sold alone and pumps sold with motors or VSDs.

1.4.5 Discussion of Potential Implementation Method

1.4.5.1 Efficiency Surfaces

DOE is considering whether any standard developed would be a function of specific speed and flow, as in the EU water pumps regulation, which would eliminate the need to develop hundreds of equipment classes based on ranges of these parameters. Flow and specific speed may be appropriate parameters on which to base efficiency. The efficiency of a pump is primarily determined by (1) size, (2) speed, and (3) ratio of the casing throat diameter to the impeller diameter [19]. The last parameter can be represented by specific speed. Research has shown that flow can be used as a proxy for the influence of the first two parameters, size and speed [19].

DOE could use the EU equation in its rulemaking as the basis for defining pump efficiency levels. DOE's preliminary investigations, however, indicate that the distribution of efficiency of the U.S. pump market is sufficiently different than that of the EU pump market that the EU's minimum pump efficiency surface does not provide a good representation of efficiency levels. For example, Figure 1.2 shows that, in the United States, the EU surfaces would eliminate from the market more ESCC pumps at low MEIs and fewer ESCC pumps at high MEIs.[19] For example, the 5% EU MEI would eliminate 13% or more of U.S. pumps, while the 80% MEI would eliminate approximately 72% of U.S. pumps. In effect, there is a significantly wider distribution of efficiencies in the United States than in the EU. Appendix B contains examples for other equipment classes. DOE recognizes that its current database may not be fully representative of the entire U.S. pump market and a revised database could show a better match with the EU market.

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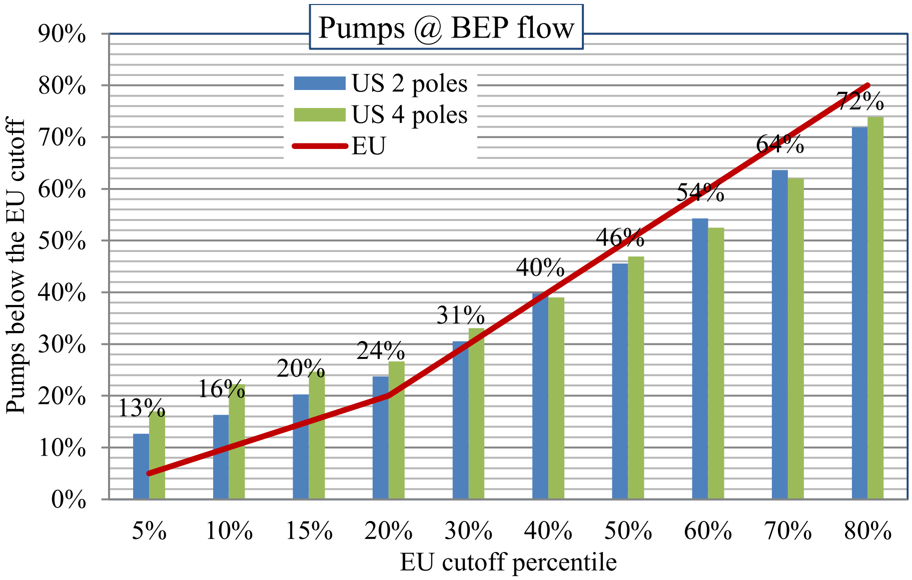
[19] U.S. data are based on a database of pump models and performance data compiled using PUMP-FLO™ Desktop, a pump selection tool from Engineered Software. This tool provides performance data at five to six flow and head points for each pump from the catalogs of 115 manufacturers or brands, representing approximately 50% of the market. DOE removed from the database the 50 hz catalogs and various forms of wastewater and sealless pumps, as well as some other pumps not proposed for coverage. DOE then attempted to classify these pumps into coverage categories based on information gathered from websites.



Note: The chart labels show U.S. percentages for 2-pole pumps.

Figure 1.2 Comparison of EU MEIs to US Market for ESCC Pumps (Based on BEP Only)

DOE could potentially address the problem of the U.S. market not matching the EU market simply by changing the C values as desired to represent a given efficiency level. (As mentioned in section 1.4.1.1, the EU uses the same surface shape for all equipment classes and MEIs.) Alternatively, DOE could develop separate equations (surfaces) unique to individual equipment classes by performing regressions on the data in its database,[20,21] and change the surface shape from bottom- to top-of-market to more accurately represent the market and potential efficiency levels. For example, pumps with higher flows typically can reach higher efficiencies at BEP compared to smaller flow pumps. As the surface moves from bottom-to-top, DOE can account for the fact that the difference in efficiency from bottom- to top-of-market for higher flow pumps is much smaller than the difference for smaller flow pumps; the surface will become flatter and flatter from bottom to top of market. DOE could develop all these surfaces using the same equation form as the EU, but with different coefficients for each parameter in the equation (not just the C value).[22] Details regarding the coefficients and equations can be found in Appendix C.

Figure 1.3 shows an example of a surface that DOE developed to represent the average ESCC market (based on model availability), compared to the EU MEI 50% level. Figure 1.4 shows the U.S. average ESCC surface again, along with a bottom-of-market and top-of-market surface. Figure 1.5 shows a 2D “slice” of the 3D surfaces for the specific speed range of 1,500 to

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[20] DOE seeks additional data to create unique surfaces for the radially split and axially split multi-stage equipment categories. DOE currently has on the order of 1,000 or more pumps for the remaining equipment classes, although these numbers could decrease based on the definition of clean water and the employment of flow, head, or power limits for coverage.

[21] Researchers in the EU note that they did not change the surface by pump type because the main hydraulic components (impeller and volute) for the pumps in scope are not very different.

[22] Note that the coefficients and surfaces shown in this section are for ESCC pumps of all poles or design speeds. Separate surfaces based on design speed are discussed further in section 3.2.3 as part of a larger equipment class discussion.

2,500. This slice demonstrates the flattening of the surface from bottom- to top-of-market. These surfaces are meant to be examples of surface development methodology only, and further discussions on choosing the baseline and market maximum surfaces can be found in sections 5.4 and 5.5, respectively. As mentioned previously, DOE recognizes that its current database may not be fully representative of the entire pumps market. As such, any efficiency surfaces developed are subject to change and are shown here only to demonstrate a potential methodology. Appendix C also contains a discussion on the influence of the exact definition of clean water pumps on the surface development.

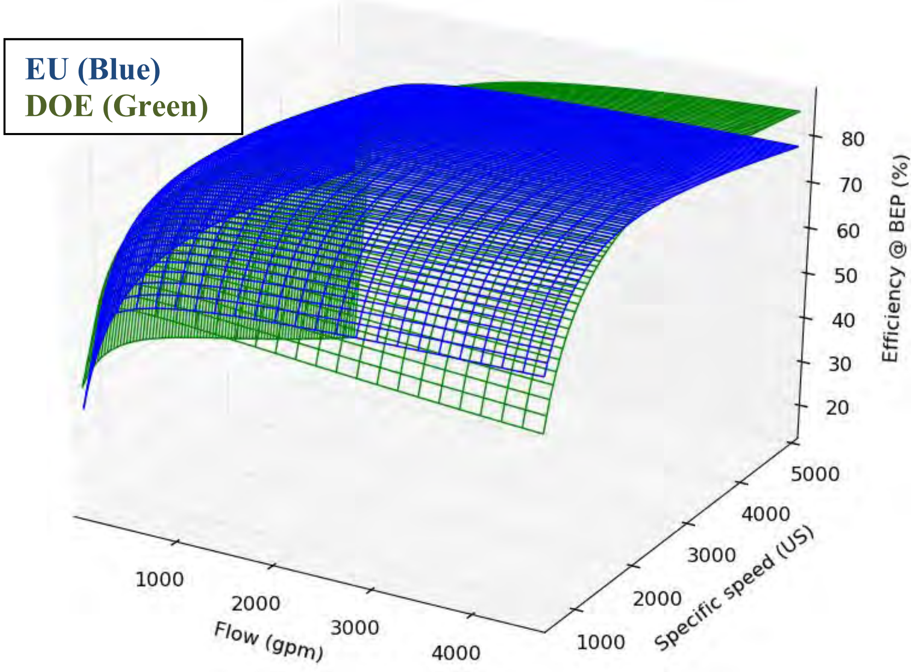


Figure 1.3 Comparison of DOE ESCC Average Surface with EU MEI 50% 4-Pole Surface

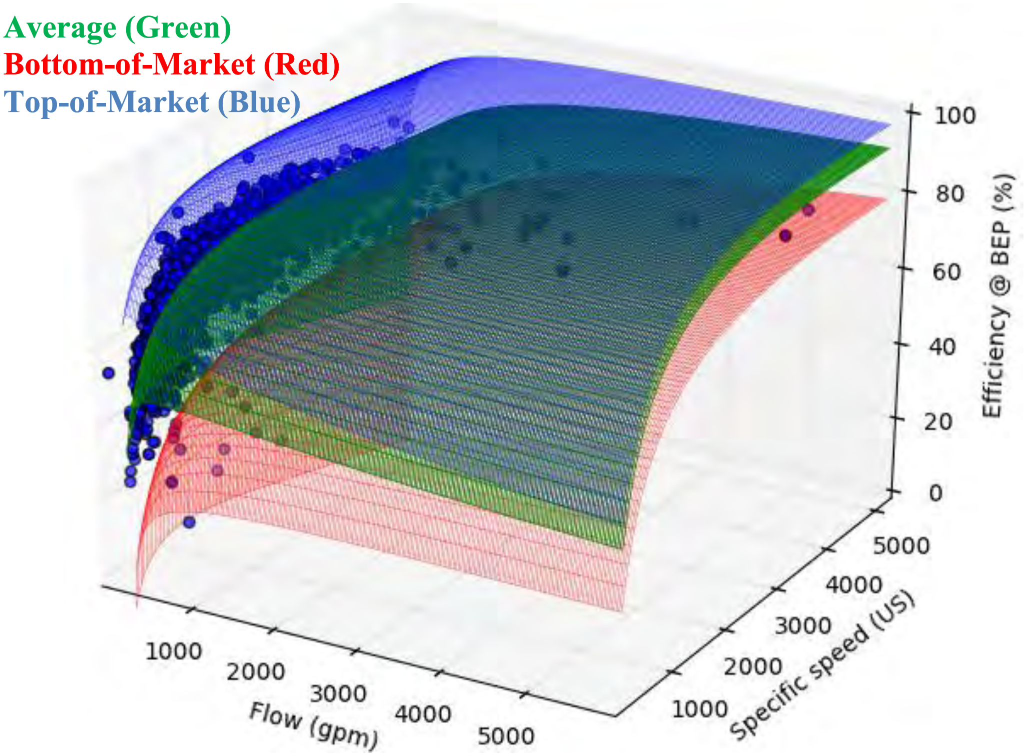


Figure 1.4 Example Average, Top-of-Market, and Bottom-of-Market Efficiency Levels for ESCC Pumps

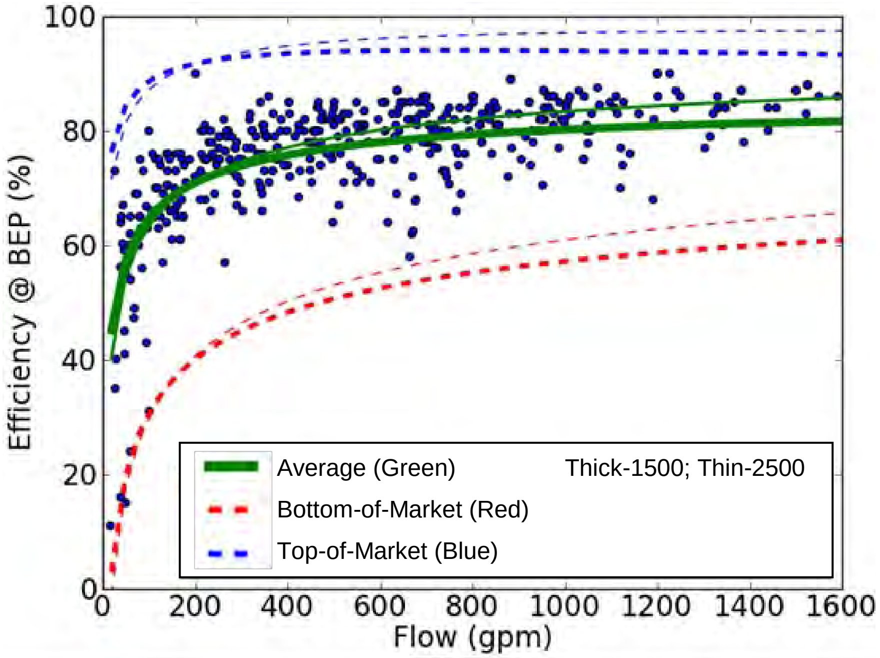


Figure 1.5 Example 2D Specific Speed "Slice" (Ns=1500-2500) Showing Average, Top-of-Market, and Bottom-of-Market Efficiency Levels for ESCC Pumps

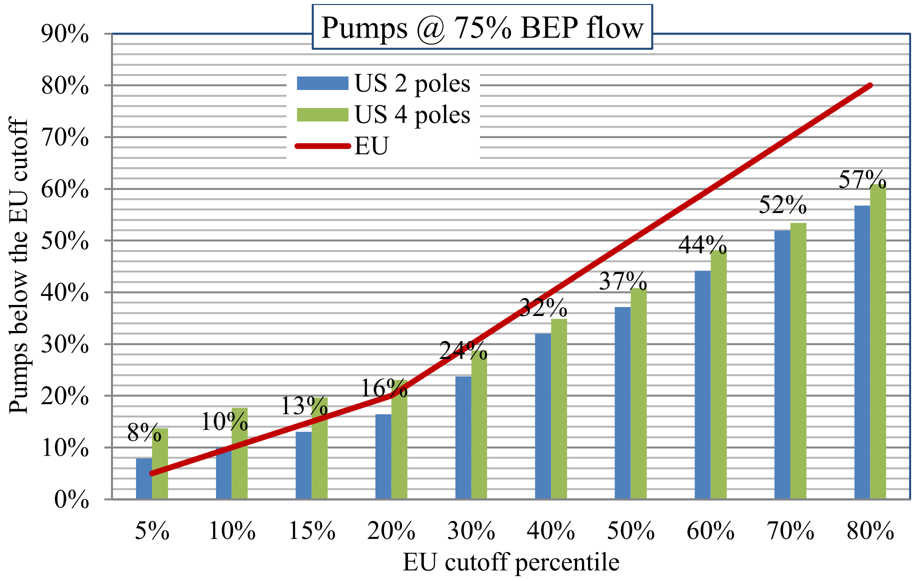
Item 1-36 DOE seeks comment regarding the implementation methodology described in this section, including whether basing efficiency on flow and specific speed is appropriate and, if so, whether the EU surface should be used as is, with adjusted Cs, or with modified shapes (adjustment of all coefficients). The last option would allow type- and efficiency level-specific surfaces. DOE also seeks comment on whether other parameters or combinations of parameters would be more appropriate or easier to implement, such as flow and head (instead of specific speed).

Item 1-37 DOE requests data that would help it improve its database, specifically performance data (i.e., head, flow, power, and efficiency at BEP and multiple additional points) for clean water pumps from catalogs not available on PUMP-FLO.

Item 1-38 DOE seeks comment on how to calculate specific speed (with regard to flow) for double suction axial split pumps and axially split multi-stage pumps with a double-suction first stage (i.e., whether to use total flow ore one-half the flow).

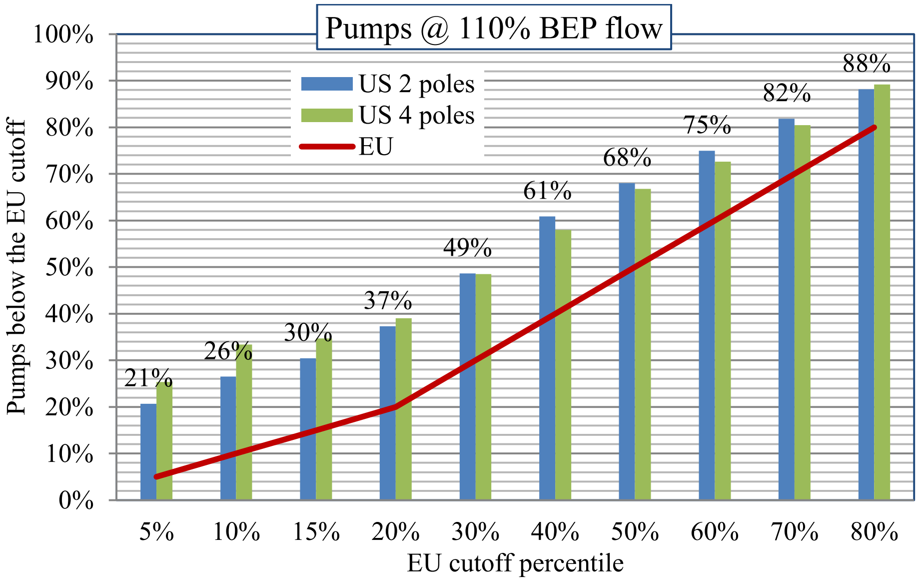
1.4.5.2 Standards for Off-Design Performance

DOE may also consider having a three-point efficiency metric. As mentioned in section 1.4.1.1, the EU requirement for part-load (75% of BEP flow) is 0.947 times the requirement at BEP, and the requirement for over-load (110% of BEP flow) is 0.985 times the requirement at BEP. For ESCC pumps in DOE's database, efficiency at 75% BEP flow is on average 0.951 times efficiency at BEP, and efficiency at 110% BEP flow is 0.985 times efficiency at BEP; the values are similar for ESFM. While these values are very similar to those used in the EU, an analysis of individual pumps compared to their EU minimum required efficiency at part-load and over-load indicates that application of the EU part-load and over-load standards would have a different result when applied to pumps in the U.S. market. This is demonstrated in Figure 1.6 and Figure 1.7, and additional figures can be found in Appendix B. However, it is important to note that these results are impacted by the appropriateness of the EU's surface, which may also not necessarily represent the U.S. market at BEP.



Note: U.S. percentages shown for 2-pole pumps only.

Figure 1.6 Comparison of EU MEIs to US Market for ESCC Pumps (75% BEP)



Note: U.S. percentages shown for 2-pole pumps only.

Figure 1.7 Comparison of EU MEIs to U.S. Market for ESCC Pumps (110% BEP)

Item 1-39 DOE seeks test data for pumps at 75% and 110% BEP flow points that would allow it to better analyze potential efficiency levels for these points.

1.4.5.3 Other Considerations

In addition, DOE is considering requiring testing based on three stages for radially split multi-stage pumps and nine stages for submersible pumps, as in the EU approach.[23] However, DOE believes that because axially split multi-stage pumps are not cellular in nature, those pumps would have to be tested in the stage configuration in which they are sold.

DOE is also considering whether to follow the EU approach in which the standard is based on the energy efficiency of pumps with a full impeller. Pump manufacturers typically design fewer pump housings than impeller sizes for cost reasons. A given pump housing can be sold with a full impeller or with reduced diameter impellers, down to approximately 80% of full diameter. Efficiency at reduced diameters is generally less than with a full diameter. However, many in the industry advocate purchasing a pump with a reduced impeller diameter, so that when load increases in the future, only the impeller has to be replaced rather than the entire pump. On the other hand, trimming impellers is a common practice in the field to bring the pump operation closer to the desired duty point.

Improving the efficiency of pumps can be achieved through use of a full impeller, which would result in the design and manufacture of additional sizes of pump casings. Increasing the variety of available pump casings would likely be extremely cost prohibitive for manufacturers, however, and would have no benefits if pumps were not correctly sized.

Item 1-40 DOE requests comment on the appropriateness of setting a standard based on a full impeller.

Item 1-41 DOE requests comment on standards based on certain numbers of stages for radially split multi-stage and submersible pumps. DOE also seeks comment on whether the same approach could be taken for axially split multi-stage pumps.

Item 1-42 DOE requests data on the percent of pumps sold with a full impeller, as well as the distribution of pump sales with reduced impellers (as a percentage of full impeller).

1.5 Test Procedures

Manufacturers must use a DOE prescribed test procedure to establish compliance with any standards adopted and make representations of energy efficiency for commercial and industrial pumps. DOE also uses the established test procedure to subsequently verify the performance of covered equipment once standards have been established. Thus, in conjunction with considering setting standards for commercial and industrial pumps, DOE is also considering a test procedure rulemaking that would define the requisite DOE test procedure for all covered commercial and industrial pumps. DOE intends for the test procedure to include an efficiency descriptor and the methods necessary to adequately measure the performance of the pump for the purposes of determining compliance with energy conservation standards.

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[23] If this number of stages is not offered within the specific product range, the next higher number of stages within the product range is to be chosen for testing.

When establishing or amending test procedures, DOE reviews existing industry test procedures currently used to measure the energy use or energy efficiency of the covered equipment. DOE then considers whether to: (1) adopt a test procedure(s) in its entirety, (2) adopt portions of a test procedure(s) with modification or additions, or (3) develop a new test procedure if existing test procedures do not provide necessary energy use or efficiency methods necessary to calculate DOE's energy use or efficiency metrics. In addition, DOE's test procedures consider ambient test conditions, repeatability and tolerances on test conditions and results, and calibration and accuracy of test equipment, among other things. Table 1.9 shows a number of test procedures that relate to the pumps for which DOE is considering establishing standards.

Table 1.9 Overview of Currently Available Pump Test Procedures

Test Procedure	Origin	Notes
ANSI/HI 14.6-2011 Rotodynamic Pumps for Hydraulic Performance Acceptance Tests	U.S.	Harmonized with ANSI/HI 11.6 and ISO 9906-2012
ANSI/HI 11.6-2012 Submersible Pump Tests	U.S.	Harmonized with ANSI/HI 14.6
ISO 9906-2012 Rotodynamic pumps – Hydraulic performance acceptance tests – Grades 1, 2 and 3	International	Harmonized with ANSI/HI 14.6
ISO 5198-1999 Centrifugal, mixed flow, and axial pumps. Code for hydraulic performance tests. Precision class	International	Provides guidance for measurement of very high accuracy. Includes specification of an optional thermodynamic method for direct measurement of efficiencies.
AS 2417-2001 Rotodynamic pumps - Hydraulic performance acceptance tests - Grades 1 and 2	Australia	Based on ISO 9906
GB/T 3216-2005	China	Based on ISO 9906
NOM-010-ENER-2004 Submersible deep well clean water motor pumps	Mexico	Based on ISO 9906
NOM-001-ENER-2000 Vertical turbine pumps with external vertical electric motor for pumping clean water for irrigation, municipal supply, or industrial supply	Mexico	Based on ISO 3555 (predecessor to 9906)

DOE will review these test procedures, along with additional test procedures that may not be listed in Table 1.9, in the test procedure rulemaking. In discussions with stakeholders, DOE determined that ANSI/HI 14.6-2011 - *Rotodynamic Pumps Hydraulic Performance Tests*, ANSI/HI 11.6-2001 - *Submersible Pump Tests*, and ISO 9906-2012 - *Rotodynamic Pumps - Hydraulic Performance Acceptance Tests- Grades 1, 2 and 3* are the most widely used in the industry. DOE, in its test procedure development, aims to align its test procedure with existing and widely used industry test procedures to the extent possible, to limit unnecessary burden on manufacturers. DOE discusses its preliminary review of these test procedures and approaches in section 1.5.1.

1.5.1 Preliminary Discussion of Approaches

In the test procedure rulemaking, DOE will consider methods that are not unduly burdensome to conduct for measuring the energy efficiency, energy use, or average annual operating cost of covered pumps during a representative average use cycle or period of use. (42 U.S.C. 6314(a)(2)) In prescribing new test procedures, DOE takes into account relevant information including technological developments relating to energy use or energy efficiency of pumps. The test procedure will be specifically designed to produce results consistent with the metrics discussed in section 1.4.

The ANSI and HI test procedures ANSI/HI 14.6-2011 and 11.6-2012, and the International Organization for Standardization (ISO) 9906-2012 procedure for rotodynamic pumps, define uniform methods for conducting laboratory tests to determine flow rate, head, power, and efficiency at a given speed of rotation. These test methods employ similar metrics, test conditions, and protocols.

ANSI/HI 14.6-2011 and 11.6-2012 and ISO 9906-2012 are conventional test methods requiring measurements of actual flow of the pumped liquid. Test methods specified in ANSI/HI 14.6-2011 and ISO 9906-2012 apply to any size centrifugal, mixed, and axial flow rotodynamic pump (without fittings) using any pumped liquid behaving as clear water. ANSI/HI 14.6-2011 and ISO 9906-2012 also allow for the use of alternative homogenous liquids[24] when water is not appropriate for the application. ANSI/HI 14.6-2011 and ISO 9906-2012 mirror each other sufficiently and include methods to measure performance of the covered products such that DOE believes ANSI/HI 14.6-2011 is applicable for testing all commercial and industrial pumps proposed for coverage in Table 1.1.

In contrast, test methods described in ANSI/HI 11.6-2012 apply only to centrifugal submersible pumps (close coupled impeller pump/motor unit) driven by induction motors and designed to operate submerged in liquid with the exception of submersible vertical turbine pumps. ANSI/HI 11.6-2012 also requires the test be performed with clean water. DOE understands that this test method is specific to submersible pumps and has similar metrics and test methods to ANSI/HI 14.6-2011. As such, ANSI/HI 11.6-2012 may be more appropriate for submersible pumps and better account for test conditions and specific test requirements when the pump and motor are fully submerged in the pumping fluid.

As another approach, DOE could consider a test procedure based on fundamental thermodynamic principles, such as ISO 5198-1999. This test standard does not require actual measurement of flow, but rather relies on temperature and pressure measurements at both the suction and delivery sides of the pump. The differential pressure and temperature across the pump are then used to determine the energy lost due to inefficiency.

As discussed in section 1.3.2, DOE may define commercial and industrial pumps inclusive of motors and VSDs. ANSI/HI 14.6-2011 provides a potential basis for testing overall system efficiency (wire-to-water) with motors and VSDs, using a wattmeter to measure the input power to the motor or VSD, as opposed to the input power to the pump. ANSI/HI 14.6-2011 also

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[24] Maximum viscosity limits apply when liquids other than water are appropriate for the application.

describes a "string" test that relies on rated efficiencies of the motor or VSD, or both, to determine the pump efficiency (as a component of overall system efficiency); however, the rating attained through the string tests in ANSI/HI 14.6-2011 is less accurate than when the pump is tested by itself. ANSI/HI 11.6-2012 also provides for the calculation of either pump efficiency or overall efficiency for submersible pumps.

ANSI/HI 14.6-2011 provides specifications for a test and suggestions regarding measurement equipment in Appendix I, as well as calibration requirements in Appendix J. Because test accuracy and repeatability can vary based on the sensitivity and calibration of the selected measurement equipment, it is important for DOE to consider the impact of different measurement instruments on test results.

For certain commercial equipment, DOE also allows the use of specific approved calculation methods to determine the rated efficiency of a certain piece of equipment based on a similar piece of equipment that has been physically tested. This can reduce the burden of test on manufacturers. ANSI/HI 14.6-2011 Appendix K includes scaling methods that can be used to translate the behavior of a model to that of a geometrically, kinematically, and dynamically similar prototype pump which has not been tested. DOE is considering the impacts of scaling on the accuracy of the calculated rated efficiency of some pump models

As part of DOE's test procedure rulemaking, DOE will also consider establishing tolerances on test conditions and test results and defining the number of units that should be tested. DOE's certification, compliance, and enforcement (CCE) requirements, located at 10 CFR 429, typically require a minimum of two unique units be tested to calculate the average certified rating for basic models that require testing.

If DOE references ANSI/HI 14.6-2011, DOE is considering requiring that tests conform to "Grade 1" tolerances for the purposes of certification with DOE energy conservation standards. As is allowed in ANSI/HI 14.6-2011, DOE is considering allowing for larger tolerances for pumps with input power of less than 10 kW (13 hp). In this case, DOE may also consider increasing the number of units tested for small shaft power pumps to increase the repeatability and accuracy of the certified rating.

Item 1-43 DOE requests comment on the use of the ANSI/HI 14.6-2011, ANSI/HI 11.6-2012, , ISO 9906-2012, and ISO 5198-1999 test procedures, as well as any other test procedures, as a basis for the development of a DOE test procedure, including any modifications or additions that may be necessary.

Item 1-44 DOE requests comment on the scope of each test procedure with respect to the equipment for which DOE is considering standards, as well as any limitations of these test procedures.

Item 1-45 DOE is also interested in the pros and cons of using a thermodynamic approach to determining pump or pumping system efficiency, as in ISO 5198-1999.

Item 1-46 DOE requests comment on use of "Grade 1" from ANSI/HI 14.6-2011 tolerances for all pump categories and whether it places any additional burden associated with performing testing requirements for all covered equipment classes.

Item 1-47 DOE requests comment on the applicable test procedures for complete pump, motor, and VSD system packages.

Item 1-48 DOE requests comment on the accuracy of different measurement equipment used to measure pump power, input power to a motor or VSD, pump flow, head, or other parameters and their impact on the accuracy of the measured pump efficiency. DOE also requests comment on the calibration frequency required to maintain sufficient equipment accuracy.

Item 1-49 DOE requests comment on the applicability of calculation methods to determine rated pump efficiencies from similar, tested pump efficiencies.

Item 1-50 DOE requests comment on the number of unique pump models manufacturers would have to test, as well as the ability for a calculation method to reduce testing burden. DOE also requests comment on the reduction in test accuracy when using a calculation method to determine rated efficiency of a unit.

1.6 Overview of the Rulemaking Process and Stakeholder Participation

Under EPCA, any new or amended standards must achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. In setting any new or amended standards, DOE must consider: (1) the economic impact of the standard on the manufacturers and consumers of the affected products; (2) the savings in operating costs throughout the estimated average life of the product compared to any increases in the initial cost or maintenance expense; (3) the total projected amount of energy savings likely to result directly from the imposition of the standard; (4) any lessening of the utility or the performance of the products likely to result from the imposition of 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 imposition of the standard; (6) the need for national energy conservation; and (7) other factors the Secretary considers relevant. (42 U.S.C. § 6295(o)(2)(B)(i) and 42 U.S.C. § 6316(a))

As discussed in further detail below, the standards rulemaking process typically includes four steps for a given consumer product or commercial/industrial equipment type: (1) the publication of a framework document in which DOE describes the overall approach it is considering in developing potential energy conservation standards for a particular product or equipment; (2) the publication of a preliminary analysis that focuses on the analytical methodology DOE is considering in setting potential standards; (3) the issuance of a notice of proposed rulemaking (NOPR); and (4) the issuance of a final rule. At each of the first three steps, DOE holds a public meeting and solicits comments from the public on a variety of relevant issues under consideration in developing potential standards.

A brief description of the next steps in DOE's process follows:

- *Preliminary Analysis* (section 1.6.1). The preliminary analysis presents a discussion of comments received on the framework document and is designed to publicly vet the models and tools that DOE intends to use in the rulemaking. Using these models and tools, DOE performs preliminary analyses to assess candidate standard levels (CSLs), which span the range of efficiencies from baseline equipment to the most efficient technology.
- *Notice of Proposed Rulemaking (NOPR;* section 1.6.2). The NOPR presents a discussion of comments received in response to the preliminary analysis; DOE's analysis of the impacts of potential standards on consumers, manufacturers, and the nation; DOE's weighting of these impacts; and any proposed standard levels for public comment.
- *Final Rule* (section 1.6.3). The final rule presents a discussion of comments received in response to the NOPR, revised analyses, as appropriate, of the impacts of any standards, DOE's weighting of those impacts, and the standard levels, if any, that DOE is adopting. The final rule also establishes the date by which manufacturers must comply with any standards.

DOE encourages interested parties to develop and submit joint recommendations and will carefully consider such recommendations in its decision making. DOE will also post to the website analytical tools, analysis, and data as soon as it becomes available.

1.6.1 Preliminary Analysis

As part of its energy conservation standards rulemaking activity, DOE typically identifies equipment technology options and makes a preliminary determination as to whether to retain each option for detailed analysis or to eliminate it from further consideration. This process includes a market and technology assessment (section 0) and a screening analysis (section 4). DOE applies four screening criteria in the screening analysis to determine which technology options to eliminate from further consideration: (1) technological feasibility; (2) practicability to manufacture, install, and service; (3) adverse impacts on equipment utility or availability; and (4) adverse impacts on health or safety. Technologies that pass through the screening analysis are evaluated, and referred to as design options, in the engineering analysis.

DOE consults with interested parties and researches industry literature to identify the design options or efficiency levels that DOE will consider in the rulemaking.

DOE considers design options or efficiency levels for each equipment class. DOE uses these design options or efficiency levels to collect manufacturer cost data, historical shipment data, shipment-weighted average efficiency data, and preliminary manufacturer impact data (*e.g.*, capital conversion expenditures, marketing costs, and research and development (R&D) costs).

Using these data, DOE conducts other analyses as part of the preliminary analysis, including:

1. engineering analysis (section 5);
2. markups analysis (section 6);

3. energy use analysis (section 7);
4. consumer life-cycle cost (LCC) and payback period (PBP) analyses (section 8);
5. shipments analysis (section 9);
6. national impact analysis (NIA), which considers national energy savings (NES) and consumer net present value (NPV) (section 10); and
7. preliminary manufacturer impact analysis (MIA) (section 12).

DOE will present the results of these analyses in the preliminary analysis technical support document (TSD).

Based on the preliminary results of these analyses, DOE selects CSLs from the energy efficiency levels considered in the preliminary analysis. In addition to the efficiency level corresponding to the maximum technologically feasible ("max-tech") efficiency level, DOE generally considers efficiency levels or design options that span the full range of technologically achievable efficiencies. The range of efficiency levels DOE typically analyzes includes the following:

- The baseline efficiency level, which typically represents equipment with the lowest energy efficiency on the market. For equipment where minimum energy conservation standards already exist, the baseline efficiency level is typically defined by the existing energy conservation standard.

- The highest energy efficiency level or lowest energy consumption level that is technologically feasible (*i.e.*, max-tech).

- Levels that incorporate noteworthy technologies or fill large gaps between other efficiency levels being considered.

DOE uses analytical models and tools to assess the different equipment classes at each efficiency level analyzed. Many of these analytical models and tools are in the form of spreadsheets used to conduct the LCC and PBP analyses and to determine the NES and NPV of prospective standards. Discussion of various CSLs in the preliminary analysis helps interested parties review the spreadsheet models that underpin the analyses. DOE uses comments from interested parties to refine the models for the next stage of the rulemaking analyses.

DOE makes the spreadsheet tools and results of the preliminary analysis available on its website for review.[25] When it publishes the preliminary analysis, DOE also makes a preliminary TSD available, which contains the details of all the analyses performed to date. After publication of the preliminary analysis, DOE provides a public comment period and holds a public meeting to discuss these analyses.

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[25] All materials associated with the rulemaking for pumps, product test procedures, and energy conservation standards are available on DOE's website at: http://www1.eere.energy.gov/buildings/appliance_standards/commercial/commercial_industrial_pumps.html

1.6.2 Notice of Proposed Rulemaking

In developing the NOPR, DOE considers the comments received during the comment period on the preliminary analysis. This process can result in revisions to the analyses conducted during the preliminary analysis stage. DOE conducts additional economic and environmental impact analyses for the NOPR. These analyses generally include:

1. LCC analysis for user subgroups (section 11);
2. complete MIA (section 12);
3. utility impact analysis (section 15);
4. employment impact analysis (section 16);
5. emissions analysis (section 13);
6. monetization of emissions (section 14); and
7. regulatory impact analysis (section 17).

DOE describes the methodology used and makes the results of all the analyses available on its website for review. This analytical process results in the selection of proposed standard levels, if any, that DOE presents in the NOPR. DOE selects the proposed standard levels from the trial standard levels (TSLs) analyzed during the NOPR phase of the rulemaking.[26] The NOPR is published in the *Federal Register* and describes the evaluation and selection of any proposed standards levels, along with a discussion of other TSLs considered but not selected and the reasons DOE did not select them.

For each equipment class, DOE identifies the max-tech efficiency level. If DOE proposes a lower level, DOE explains the reasons for eliminating higher levels, beginning with the highest level considered. DOE presents the analytical results in the NOPR and provides the details of the analysis in an accompanying TSD.

DOE considers many factors in selecting proposed standards. These factors are prescribed by EPCA and take into consideration the benefits and costs of energy conservation standards.

When DOE publishes the NOPR, it provides the U.S. Department of Justice (DOJ) with copies of the NOPR and TSD to solicit feedback on the impact of any proposed standard levels on competition in the market of the products that are the subject of the rulemaking. DOJ reviews standard levels to assess the impacts from any lessening of competition likely to result from the imposition of such standards. (42 U.S.C. § 6295(o)(2)(B)(i)(V) and (B)(ii)) Publication of the NOPR is followed by a public comment period that includes a public meeting.

1.6.3 Final Rule

After publication of the NOPR, DOE considers public comments received on the proposal and accompanying analyses. DOE reviews the engineering and economic impact analyses and any proposed standards, based on these comments, and considers modifications

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[26] TSLs are assembled from the candidate standard levels (CSL) analyzed for the individual equipment classes, based on a set of criteria from the analysis results.

where necessary. DOE also considers DOJ's comments on the NOPR relating to the impacts of any proposed standard levels on competition to determine whether changes to these standard levels are needed. DOE publishes the DOJ comments and DOE's response as part of the final rule.

In any final rule, DOE sets any final standard levels and the compliance date and also explains the basis for the selection of such standard levels. The final rule is accompanied by a final TSD.

1.6.4 Labeling

Title III of the Energy Policy and Conservation Act of 1975 (EPCA), as amended (42 U.S.C. 6291 et seq.), includes provisions for labeling (42 U.S.C. 6315). If DOE prescribes test procedures for pumps, DOE must determine if the following criteria are met before prescribing a labeling rule: (1) labeling in accordance with this section is technologically and economically feasible with respect to such class; (2) significant energy savings will likely result from such labeling; and (3) labeling in accordance with this section is likely to assist consumers in making purchasing decisions (42 U.S.C. 6315(h)).

Section 6315 of EPCA specifies certain aspects of equipment labeling that DOE must consider in any rulemaking establishing labeling requirements for covered equipment. At a minimum, such labels must include the energy efficiency of the equipment to which the rulemaking applies, as tested under the prescribed DOE test procedure. In addition, the labeling rulemaking may consider the addition of other specifications for equipment labels, including: directions for the display of the label; a requirement to display on the label additional information related to energy efficiency or energy consumption, which may include instructions for maintenance and repair of the covered equipment, as necessary to provide adequate information to purchasers; and requirements that printed matter displayed or distributed with the equipment at the point of sale also include the information required by the labeling rule to be displayed on the label. (42 U.S.C. 6315(b) and 42 U.S.C. 6315(c)). For more information, see DOE's Request for Information on labeling for commercial and industrial equipment 77 FR 75400 (December 20, 2012).

DOE could analyze the appropriateness of a labeling rule in conjunction with the analyses for standards described in the remainder of this document. The stakeholders have expressed interest in DOE establishing a label to reflect pump efficiency and other critical application parameters.

Item 1-51 DOE seeks comment on whether a labeling rule would be technologically or economically feasible, result in a significant conservation of energy, or assist customers in making purchasing decisions.

Item 1-52 DOE seeks comment on information that it should consider requiring for display on any prospective label, as well as factors DOE should consider regarding the size, format, and placement of any such label.

2. OVERVIEW OF ANALYSES FOR RULEMAKING

The purpose of the analyses is to support DOE's determination on whether to establish energy conservation standards for pumps. The analyses ensure that, if standards are established, DOE selects standards that achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified and will result in significant energy savings, as required by EPCA. Economic justification includes the consideration of the factors set forth in EPCA (see Section 1.1 of this framework document), which encompass the economic impacts on domestic manufacturers and consumers, national benefits including environmental impacts, issues of consumer utility, and impacts from any lessening of competition.

Figure 2.1 summarizes the analytical components of the DOE standards-setting process. The analyses are presented in the center column. Each analysis has a set of key inputs, which are data and information required for the analysis. "Approaches" are the methods that DOE will use to obtain key inputs. The results of each analysis are key outputs, which feed directly into the rulemaking. Arrows indicate the flow of information between the various analyses. DOE ensures a consistent approach to its analyses throughout the rulemaking by considering each analysis as a part of the overall standard-setting framework.

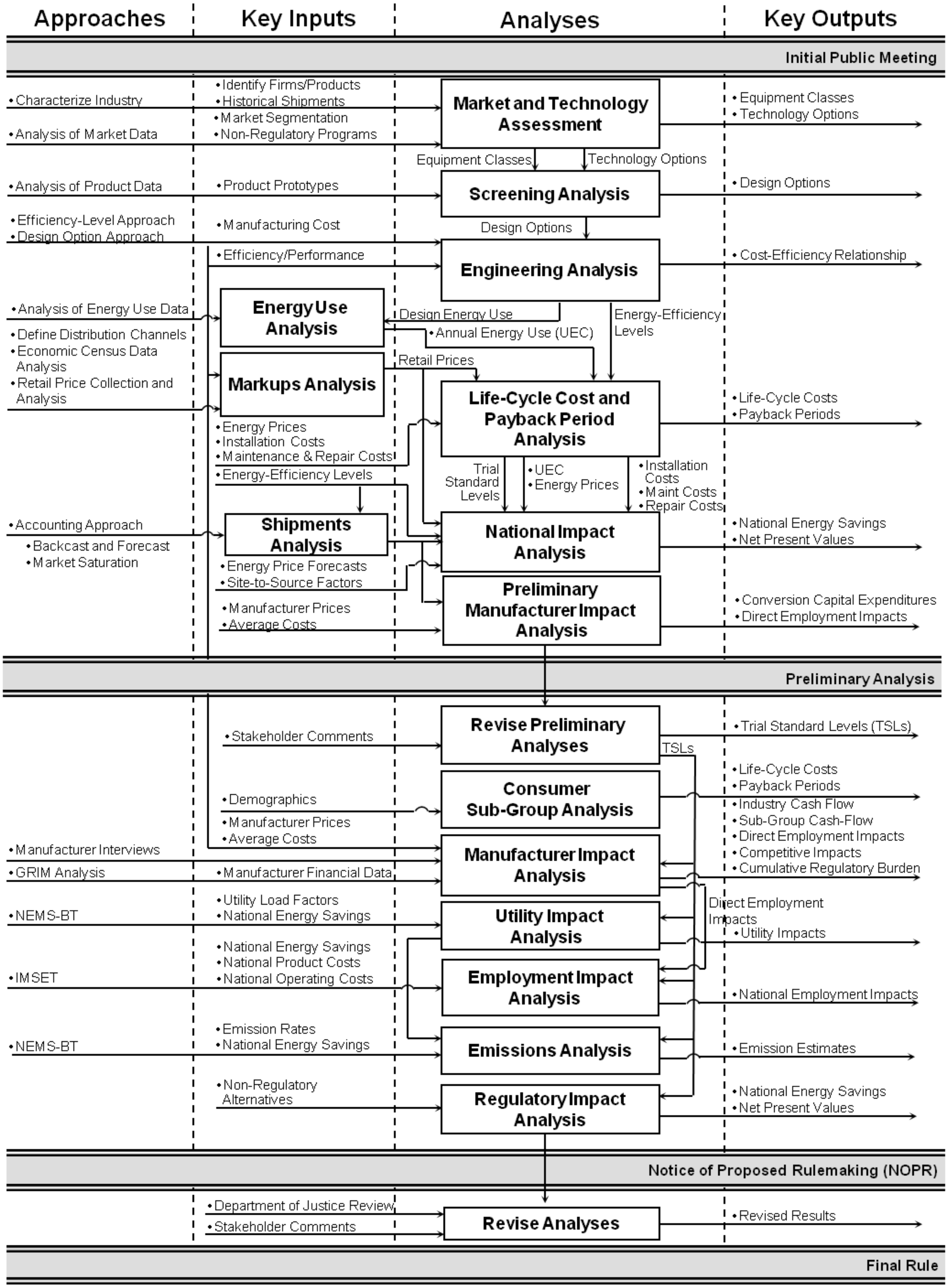

Figure 2.1 Flow Diagram of Analyses for the Pumps Standards Rulemaking Process

3. MARKET AND TECHNOLOGY ASSESSMENT

The market and technology assessment provides information about the commercial and industrial pump industries and the performance attributes of this equipment. DOE uses this assessment to determine equipment classes and identify potential design options or efficiency levels for each equipment class.

3.1 Market Assessment

DOE's market assessment identifies and characterizes the manufacturers of pumps, estimates market shares and trends, and addresses regulatory and non-regulatory initiatives intended to improve the energy efficiency or reduce the energy consumption of the pumps covered by this rulemaking.

The market assessment allows DOE to gather data that can help identify important issues (*e.g.*, potential small business impacts, competitive disruptions, and other factors that may arise from enacting standards). For example, market structure data can be used to assess competitive impacts as part of the manufacturer impact analysis.

DOE considers manufacturers, industry organizations, and other interested parties as potential sources of such information. In addition, DOE is considering examining national market reports or data collected in national energy use surveys, or extrapolating historical pump sales data from the U.S. Census Bureau. The Census Bureau publishes limited information on the quantity and dollar-value of equipment shipments. The Census Bureau data do not, however, disaggregate the pumps according to the equipment classes DOE is considering for this rulemaking.

Item 3-1 DOE requests information that would contribute to the market assessment for the pumps that would be covered in this rulemaking, especially for those equipment classes designated in section 3.2. Examples of information sought include current equipment features and efficiencies, equipment feature and efficiency trends, and historical equipment shipments and prices.

According to HI's comments on the RFI, there are approximately 450 pump manufacturers that serve the U.S. market, with nine having sales of at least one billion dollars, and 72 having sales of more than 100 million dollars. (HI, No. 6 at p. 4) HI represents 97 pump manufacturers and suppliers. (HI, No. 6 at p. 1)

In the United States, ten companies represent 60-70% of the total U.S. pumps market: Grundfos, Sulzer, Weir Group, KSB, Xylem, Flowserve, Ebara, Pentair, Roper Industries, and ITT Goulds [16]. With the exception of Roper Industries, all of these manufacturers make pumps that fall into the scope discussed in section 1.3. There has been significant consolidation in the global pump market in the past 25 years, and these ten companies comprise approximately 70 brands or divisions, shown in Table 3.1, nearly all of which used to be independent companies. In some cases the manufacturing for these brands has been consolidated, but in most cases the legacy brand names continue to be used. Table 3.2 shows major suppliers for various pump equipment categories, some but not all of which are brands of the top 10 companies.

Table 3.1 Top 10 U.S. Pump Suppliers with Major Brands/Operating Units

Parent Company	**Major Brands/Operating Units**
Grundfos	Chicago, Grundfos, Morris, Paco, Peerless, Yeomans
Sulzer	*ABS*, Johnston, Sulzer
Weir Group	*Begeman*, Envirotech, Floway, *Geho*, Hazleton, Lewis, Multiflo, Warman, *Weir*
KSB	GIW, *KSB*
Xylem	A.C., Bell & Gossett, *Flygt*, Goulds Water Technology, Godwin, Jabsco, Laing, *Lowara*, Marlow, Red Jacket
Flowserve	*ACEC*, Aldrich, Byron Jackson, Cameron, Durco, Flowserve, IDP, Lawrence, Pacific, *Pleuger*, Scienco, Sier Bath, *TKL*, United, Western Land Roller, Wilson Snyder, Worthington
Ebara	Ebara
Pentair	Aermotor, Aurora, Berkeley, Edwards, Fairbanks Morse, Flotec, Hydromatic, Hypro, *Jung Pumpen*, Layne/Vertiline, Myers, *Nocchi*, Shurflo, Simer, Sta-Rite
Roper Industries	*Abel*, Cornell, Neptune, Roper
ITT Goulds	AC, Goulds

Note: Brands/Operating units in *italics* do not have manufacturing locations in the U.S.

Table 3.2 Major Suppliers for Proposed Covered Pump Equipment Categories

	Parent company	Brand/Operating Unit	ESCC	ESFM	DS	AS/RS	VT-S	VT	A-M
Top 10 Parent Companies	Ebara	Ebara	X						
	Flowserve	Byron Jackson					X	X	
	Flowserve	Flowserve		X	X	X		X	
	Flowserve	IDP		X	X	X		X	
	Grundfos	Grundfos	X	X		X	X		
	Grundfos	Paco	X	X	X				
	Grundfos	Peerless	X	X			X	X	X
	ITT Goulds	AC							X
	ITT Goulds	Goulds	X	X	X	X	X	X	X
	KSB	KSB		X		X			X
	Pentair	Aurora	X	X	X				
	Pentair	Fairbanks Morse						X	X
	Pentair	Layne/Vertiline						X	X
	Sulzer	Johnston					X	X	X
	Sulzer	Sulzer			X	X			
	Weir Group	Floway					X	X	X
	Xylem	Bell & Gossett	X	X	X	X			
	Xylem	Goulds Water Technology	X						
Non-Top 10 Parent Companies	American Turbine Pump	American Turbine Pump						X	
	Crane Pumps & Systems	Burks	X						
	Crane Pumps & Systems	Weinman			X				
	Cascade Pump Company	Cascade Pump Company							X
	Gusher Pump	Gusher Pump				X			
	National Pump Company	National Pump Company					X	X	
	GE Water Technology	Osmonics				X			
	Price Pump Company	Price Pump Company	X						
	Ardox	Scot Pump	X						
	Simflo Pumps	Simflo Pumps						X	
	Taco	Taco	X						

3.1.2 Shipments and Value

The U.S. Census Bureau has collected data on pumps (except hydraulic) and compressors under MA333P [4]. Table 3.3 shows 2010 data for product codes that include pump types for which DOE is currently considering energy conservation standards in this rulemaking. Some of these pumps, however, may not be for clean water applications. Table 3.4 shows 2010 data[27] for product codes that include pump types that fall outside the current scope of this rulemaking. The Census Bureau also provides information on export shipments and import shipments, but these data are not disaggregated to the same extent as the manufacturer shipment data. Table 3.5 shows DOE estimates of the imports and exports disaggregated to the equipment classes. Table 3.6 shows DOE estimates of the percent of pumps by category used in clean water applications. Table 3.7 shows DOE estimates of the percent of pumps by category sold with motors by the pump manufacturer.

Item 3-2 DOE requests input on its identification of product codes in the U.S. Census data that match the equipment classes proposed for coverage in this rulemaking.

Item 3-3 DOE requests feedback on its estimates of the disaggregation of pump exports and imports to product codes, its estimates of the percentage of shipments of clean water pumps, and its estimates of the percent of shipments sold with motors by the pump manufacturer.

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[27] These data are not expected to be available for 2011 or future years because the Current Industrial Report program has been terminated. DOE seeks information on additional sources of this or similar data.

Table 3.3 U.S. Pump Manufacturer Shipments of Covered Pumps

Census Product Code	Pump Type	2010 Quantity (000s)	2010 Value (Million $)	Equipment Category	Notes
3339111448	Centrifugal single and two stage, single and end suction, close coupled with driver	1,301	191	End Suction Close Coupled	Two stage would not be covered under the current scope
3339111452	Centrifugal single-stage, single suction, frame or foot mounted, non-ANSI, non-ISO, with or without recessed impeller, all size discharge	235	133	End Suction Frame Mounted	Pumps with recessed impellers would not be covered under the current scope (solids-handling)
3339111450	Centrifugal single and two stage, single suction, in-line, close coupled with driver	95*	14*	In-Line	Two stage would not be covered under the current scope
333911144E	Centrifugal single-stage, single suction, vertical, in-line frame	29	29	In-Line	
333911144H	Centrifugal, single-stage, single suction, frame or foot mounted, metallic pumps, built to ANSI B73.1 or ISO2858	41	166	End Suction Frame Mounted	Primarily for chemicals, but some may be for clean water and would be covered under the current scope
333911145L	Centrifugal single-stage, axially split, double suction, all size discharge	13	213	Double Suction	
333911146F	Centrifugal multi-stage, single or double suction, volute or diffuser design, axially split case	1	97*	Multi-Stage Axial Split	
3339111468	Centrifugal multi-stage, single or double suction, diffuser design, radially split case	14	155*	Multi-Stage Radial Split	
3339111496	Vertical turbine pumps, including pumps with submersible motor, bowl assemblies, and can and pot type	29	175	Vertical Turbine and Submersible	
3339111486	Centrifugal propeller and mixed flow, horizontal and vertical, all sizes	1	135	Axial/Propeller and Mixed	

*Estimated values

Table 3.4 U.S. Pump Manufacturer Shipments of Non-Covered Pumps

Census Product Code	Pump Type	2010 Quantity (000s)	2010 Value (Million $)	Reason Product Code Does Not Seem to Fall in Current Scope of Coverage
3339111413	Centrifugal sewage type (nonsubmersible), vertical or horizontal with non-clog impeller, all sizes	20	243	Not clean water (solids-handling)
3339111432	Centrifugal submersible solids handling pumps, solids 1" to 2" inclusive, all hp	479	101	Not clean water (solids-handling)
3339111434	Centrifugal submersible non-clog pumps, greater than 2" solids handling capacity, all size discharge	14	58	Not clean water (solids-handling)
3339111436	Centrifugal submersible grinder pumps, all hp	94	103	Not clean water (grinder)
333911144L	Centrifugal single-stage, single suction, frame or foot mounted, nonmetallic pumps, built to National or International Standards ANSI B73.1 or ISO 2858	1	10	Not clean water (chemical process)
3339111455	Centrifugal single-stage, single suction, replaceable elastomer lined or hard metal, frame or foot mounted	2*	20*	Not clean water (slurry)
3339111458	Centrifugal single-stage, single suction, centerline mounted	74	62	Not clean water (oil)
3339111426	Centrifugal submersible effluent pumps, less than 1” solids handling capacity, all hp	287	47	Not clean water (solids-handling)
3339111488	All other centrifugal pumps (including single stage radially split double suction; and sealless)	1,308	467	Not clean water (refinery use, sealless)
33391114C7	Reciprocating pumps, driven by electric motor, engine, or steam turbine, including reciprocating piston, plunger, power-pumps for water flooding, or diaphragm (not air operated) pumps	604	311	Positive Displacement
33391114D5	Diaphragm pumps, air operated	300	234	Positive Displacement
33391114R9	Rotary pumps, 100 PSI and under, designed pressure, all GPM, designed capacity	470	148	Positive Displacement
33391114RG	Rotary pumps, 101 to 249 PSI, designed pressure, all GPM, designed capacity	193	119	Positive Displacement
33391114RN	Rotary pumps, 250 PSI and over, designed pressure	166	117	Positive Displacement
33391114T5	Other industrial pumps	208*	122*	Positive Displacement
3339111101	Domestic water systems, nonsubmersible pump systems (jet and nonjet, including drivers)	955	149	Residential
3339111108	Domestic water systems, submersible pump systems including drivers, all hp	509	111	Residential

Census Product Code	**Pump Type**	**2010 Quantity (000s)**	**2010 Value (Million $)**	**Reason Product Code Does Not Seem to Fall in Current Scope of Coverage**
3339111107	Domestic water systems, domestic hand and windmill pumps, pump jacks, and cylinders, sold separately, including drivers	20	2	Residential
3339111235	Domestic sump pumps, 1 hp and under, pedestal, including drivers	265	13	Residential
3339111242	Domestic sump pumps, submersible, including drivers, all hp	3,101	222	Residential
3339111341	Oil-well and oil-field pumps, subsurface pumps for oil-well pumping	42	223	Not clean water (oil)
3339111364	Oil-well and oil-field pumps, other oil-well and oil-field pumps, including mud pumps (slush pumps)	20	187	Not clean water (oil, slush)
3339111590	Other pumps, including drivers	2,651	381	Unknown types

*Estimated values

Table 3.5 U.S. Market Size Estimate for Pumps Proposed for the Standard

Product Code	**Product Description**	**Shipped Qty. (000 Units)**	**Import Units (000)**	**Export Units (000)**	**Market Size in 1000 Units (Shipped + Imp. - Exp.)**	**Shipped Value (Mill $)**	**Import Value (Mill $)**	**Export Value (Mill $)**	**Market Size Mill $ (Shipped + Imp. - Exp.)**
3339111448	Centrifugal single and two stage, single and end suction, close coupled with driver	1,301	4,323	73	5,551	191	169	58	302
3339111452	Centrifugal single stage, single suction, frame or foot mounted, non-ANSI, non-ISO, with or without recessed impeller, all size discharge	235	0	13	222	133	0	41	92
3339111450	Centrifugal single and two stage, single suction, in-line, close coupled with driver	95	315	5	405	14	12	4	22
333911144E	Centrifugal single stage, single suction, vertical, in-line frame	29	0	2	27	29	0	9	20
333911144H	Centrifugal single stage, single suction, frame or foot mounted, metallic pumps, built to National or International Standards ANSI B73.1 or ISO2858	41	0	2	39	166	0	*51*	*115*
333911145L	Centrifugal single stage, axially spit, double suction, all size discharge	13	0	1	12	213	0	65	148
333911146F	Centrifugal multi-stage, single or double suction, diffuser design, volute or diffuser design, axially split case	1(2)	0	0	1	97	0	30	67
3339111468	Centrifugal multi-stage, single or double suction, diffuser design, radially split case	14	0	1	13	155	0	47	108
3339111486	Centrifugal propeller and mixed flow, horizontal and vertical, all sizes.	1	0	0	1	135	0	42	93
3339111496	Vertical turbine pumps, including pumps with submersible motor, bowl assemblies, and can and pot type	29	10	10	29	175	15	77	113
	TOTAL	*1,759*	*4,648*	*107*	*6,300*	*1,308*	*196*	*424*	*1,080*

Table 3.6 U.S. Market Size Estimate for Pumps Proposed for the Standard – Clean Water

Product Code	Product Description	Market Size in 1000 Units (Shipped + Imp. - Exp.)	Estimated % Which Handles Clean Water	Size of Market for Clean Water Pumps (000 Units)	Market Size Mill $ (Shipped + Imp. - Exp.)	Estimated % Which Handles Clean Water	Size of Market for Clean Water Pumps (Mill. $)
3339111448	Centrifugal single and two stage, single and end suction, close coupled with driver	5,551	90%	4,996	302	85%	257
3339111452	Centrifugal single stage, single suction, frame or foot mounted, non-ANSI, non-ISO, with or without recessed impeller, all size discharge	222	80%	178	92	75%	69
3339111450	Centrifugal single and two stage, single suction, in-line, close coupled with driver	405	90%	365	22	85%	19
333911144E	Centrifugal single stage, single suction, vertical, in-line frame	27	50%	14	20	40%	8
333911144H	Centrifugal single stage, single suction, frame or foot mounted, metallic pumps, built to National or International Standards ANSI B73.1 or ISO2858	39	20%	8	115	10%	12
333911145L	Centrifugal single stage, axially spit, double suction, all size discharge	12	90%	11	148	70%	104
333911146F	Centrifugal multi-stage, single or double suction, diffuser design, volute or diffuser design, axially split case	1	40%	0.4	67	30%	20
3339111468	Centrifugal multi-stage, single or double suction, diffuser design, radially split case	13	80%	10	108	70%	76
3339111486	Centrifugal propeller and mixed flow, horizontal and vertical, all sizes.	1	90%	1	93	75%	70
3339111496A	Vertical turbine pumps, bowl assemblies, and can and pot type. Excludes those with submersible motor	22	90%	21	96	70%	67
3339111496B	Vertical turbine pumps with submersible motors, bowl assemblies	7	99%	6	17	99%	17
	TOTAL	*6,300*	*89%*	*5,610.4*	*1,080*	*67%*	*719*

Table 3.7 Estimate of U.S. Clean Water Pumps Sold with Motors (by Manufacturer)

Product Code	**Product Description**	**Size of Market -Clean Water Pumps (000 Units)**	**Size of Market - Clean Water Pumps (Mill. $)**	**Percent Where Pump Mfr. Supplies Motor**	**Number of Pumps Sold with Motors (000 Units)**	**Dollar Amount of Pumps Sold with Motors (Mill $)**
3339111448	Centrifugal single and two stage, single and end suction, close coupled with driver	4,996	257	75%	3,747	193
3339111452	Centrifugal single stage, single suction, frame or foot mounted, non-ANSI, non-ISO, with or without recessed impeller, all size discharge	178	69	15%	27	10
3339111450	Centrifugal single and two stage, single suction, in-line, close coupled with driver	365	19	80%	292	15
333911144E	Centrifugal single stage, single suction, vertical, in-line frame	14	8	15%	2	1
333911144H	Centrifugal single stage, single suction, frame or foot mounted, metallic pumps, built to National or International Standards ANSI B73.1 or ISO2858	8	12	15%	1	2
333911145L	Centrifugal single stage, axially spit, double suction, all size discharge	11	104	10%	1	10
333911146F	Centrifugal multi-stage, single or double suction, diffuser design, volute or diffuser design, axially split case	0.4	20	10%	0	2
3339111468	Centrifugal multi-stage, single or double suction, diffuser design, radially split case	10	76	15%	2	11
3339111486	Centrifugal propeller and mixed flow, horizontal and vertical, all sizes.	1	70	10%	0	7
3339111496A	Vertical turbine pumps, bowl assemblies, and can and pot type. Excludes those with submersible motor	21	67	10%	2	7
3339111496B	Vertical turbine pumps with submersible motors, bowl assemblies	6	17	85%	5	14
	TOTAL	*5610.4*	*719*		*4,079*	*272*

3.2 Equipment Classes

DOE may divide covered equipment into equipment classes by: (a) the type of energy used; (b) the capacity of the equipment; and/or (c) any other performance-related feature that justifies different standard levels. In determining whether any such feature justifies a different standard level, DOE considers the utility of the feature to the consumer and other factors DOE considers appropriate. (42 U.S.C. 6295(q)) DOE uses the market assessment to determine the appropriate equipment classes and their respective operating ranges. DOE will conduct its analysis to establish separate standard levels for each equipment class.

In this framework document, DOE is not differentiating equipment classes for pumps based on the type of energy used, because the majority of pumps are driven by electric motors. In addition, for those pumps driven by engines, DOE is considering a metric based only on pump efficiency.

Because DOE tentatively plans to set standards as a function of flow and specific speed, DOE is not defining equipment classes in this framework document based on capacity (*i.e.,* flow or other related parameters such as horsepower).

DOE is considering differentiating equipment classes based on the following performance-related or utility features:

- pump category (mechanical configuration),
- pump design speed, and
- motor (and control) package.

Item 3-4 DOE welcomes comments on which performance-related features or design characteristics DOE should consider to define pump equipment classes.

3.2.2 Pump Category (Mechanical Configuration)

DOE is considering establishing equipment classes for the specific pump categories set forth in Table 3.8.

Table 3.8 Rotodynamic Clean Water Pump Categories Proposed for Coverage

Pump Type	Sub-Type	Stages	DOE Terminology
End Suction	Close Coupled	Single	End Suction Close Coupled (ESCC)
	Own Bearings/ Frame Mounted	Single	End Suction Frame Mounted (ESFM)
In-Line		Single	In-Line (IL)
Axial Split		Single	Double Suction (DS)
		Multi	Axially Split Multi-Stage (AS)
Radial Split		Multi	Radially Split Multi-Stage (RS)
Vertical Turbine	Non-Submersible	Any	Vertical Turbine (VT)
	Submersible	Any	Submersible (VT-S)
Axial/Propeller and Mixed Flow		Any	Axial/Propeller and Mixed (A-M)

DOE is considering these equipment classes for the different categories of pumps designed for different applications. DOE notes that, in some areas of head and flow requirements, multiple categories of pumps can be used, and some are inherently more efficient than others. For example, at low specific speeds, adding stages may be a design option that improves efficiency. DOE recognizes, however, that there may be issues related to utility if a pump standard effectively eliminated a given pump category. For example, in retrofit situations, it may be cost-prohibitive to re-design piping to accommodate a new category of pump.

Item 3-5 DOE requests information regarding the utility of different pump categories proposed for coverage that would warrant separate equipment classes. For example, could end suction pumps be a single equipment class, or are the breakdowns shown necessary to preserve equipment utility that would affect performance? Could axially and radially split multi-stage pumps be a single equipment class? Could all vertical turbine pumps (both submersible and non-submersible) be a single equipment class?

DOE also realizes that it may need to further disaggregate the equipment categories considered for coverage to accommodate the utility of certain pumps. If DOE defines pumps inclusive of the motor or motor and controls, for example, it would also be advantageous to disaggregate equipment classes for pumps that would always be used in variable load applications.

Item 3-6 DOE requests information on whether any of the equipment proposed for coverage provides utility that requires further breakdown from the categories shown in Table 3.8. For example, do multi-stage pumps with a double suction first stage require a separate equipment class? Do vertical turbine can pumps require a separate equipment class from vertical turbine lineshaft pumps?

Item 3-7 DOE requests comment on whether equipment classes can be developed for pump categories that would always be used in variable load applications.

3.2.3 Pump Design Speed

Pump speed selection affects noise, maintenance cost, net positive suction head required (NPSHr), and controllability requirements, as well as attainable efficiency, which is why DOE may consider using it as a feature to differentiate equipment classes. The EU regulation contains separate efficiency standards for pumps operating at 1,450 rpm and pumps operating at 2,900 rpm (*i.e.*, 4-pole and 2-pole motors, equating to 1,750 rpm and 3,500 rpm in the United States) [1]. As a result of DOE's review of this approach, this section discusses: (1) the size effect captured by the EU standards that differ by design speed, (2) the implications for single pumps running at multiple speeds, and (3) DOE's options in addressing the design speed issue. To help clarify this discussion, Figure 3.1 demonstrates the difference between (1) and (2): Pumps A and B demonstrate the size effect (1), whereas Pump A and A2 demonstrate a single pump running at multiple speeds (2).[28]

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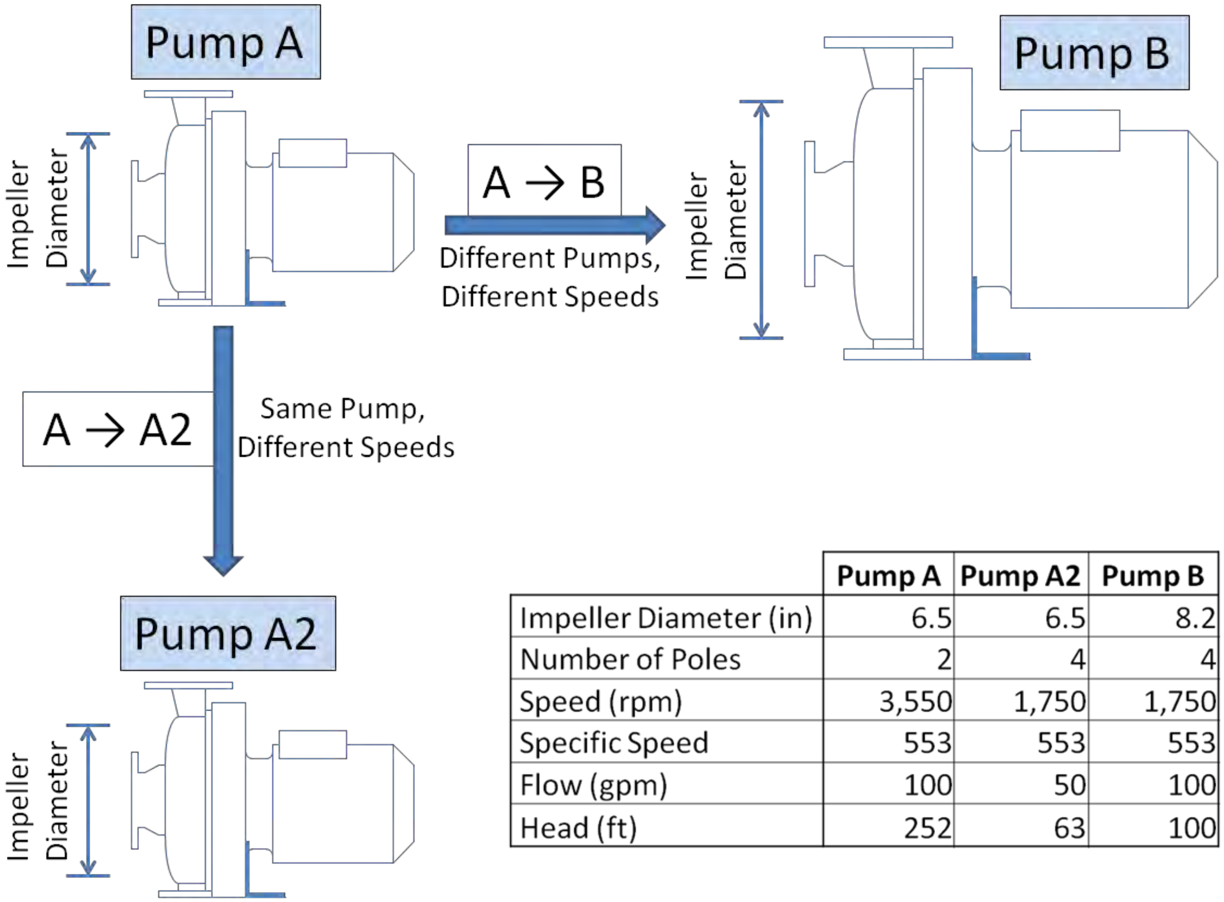
[28] Note that none of the pumps shown represents a selection option by an end user; end users choosing between pumps with different speeds would be choosing between pumps that produce the same flow and head but with different specific speeds. This scenario is not addressed in this section, which is focused on pump manufacturing rather than pump selection.



	Pump A	Pump A2	Pump B
Impeller Diameter (in)	6.5	6.5	8.2
Number of Poles	2	4	4
Speed (rpm)	3,550	1,750	1,750
Specific Speed	553	553	553
Flow (gpm)	100	50	100
Head (ft)	252	63	100

Figure 3.1 Example of Pumps Showing the Size Effect (2 Different Pumps: A and B) and the Speed Effect (Same Pump at Multiple Speeds: A and A2)

3.2.3.1 Size Effect

Using ESCC pumps as an example, the EU minimum efficiency surface for pumps with 4-pole motors is two to three points higher than the efficiency surface for pumps with 2-pole motors, depending on the standard level.[29] In other words, for a given flow and specific speed, pumps operating with 4-pole motors have better pump efficiency (and therefore higher EU efficiency standards) than pumps operating with 2-pole motors. It is important to note that this difference is not specifically related to speed, but rather to pump size. Comparing pumps with the same specific speed and flow, but at two different speeds, means comparing two geometrically similar pumps—a smaller pump running at higher speed and a larger pump running at lower speed (such as Pumps A and B in Figure 3.1). The EU's standard indicates that the latter is more efficient.

DOE notes that other pump resources show efficiency as a function of flow and specific speed without regard to speed or physical size [11,18, 19]. See Figure 3.2 for an example. These resources may be relying on Anderson, who concluded after the analysis of true Reynolds number and direct flow quantity that the latter is a sufficiently accurate arbiter for the efficiency

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[29] Compare the values for C for 1,450 rpm and 2,900 rpm pumps in Table 1.5, for example. Note that, the higher the C value, the lower the minimum efficiency (because C is subtracted in the equation).

of a group of pumps [19]. Anderson goes on to state that "the efficiency of a small pump at high speed can be the same as a large pump at low speed, providing the shape number [specific speed] and flow are kept the same. That is the reason why [figures] can, in general, show efficiency against quantity [flow] and shape number [specific speed] without reference to physical size or operating speed." However, a Europump Guide notes that, when using flow instead of Reynolds number along with specific speed to predict efficiency, the efficiency at speeds other than 2,900 rpm may be different than that predicted [20]. Because predicted efficiency varies with design speed, this indicates that flow is not actually a sufficient determiner of pump efficiency.

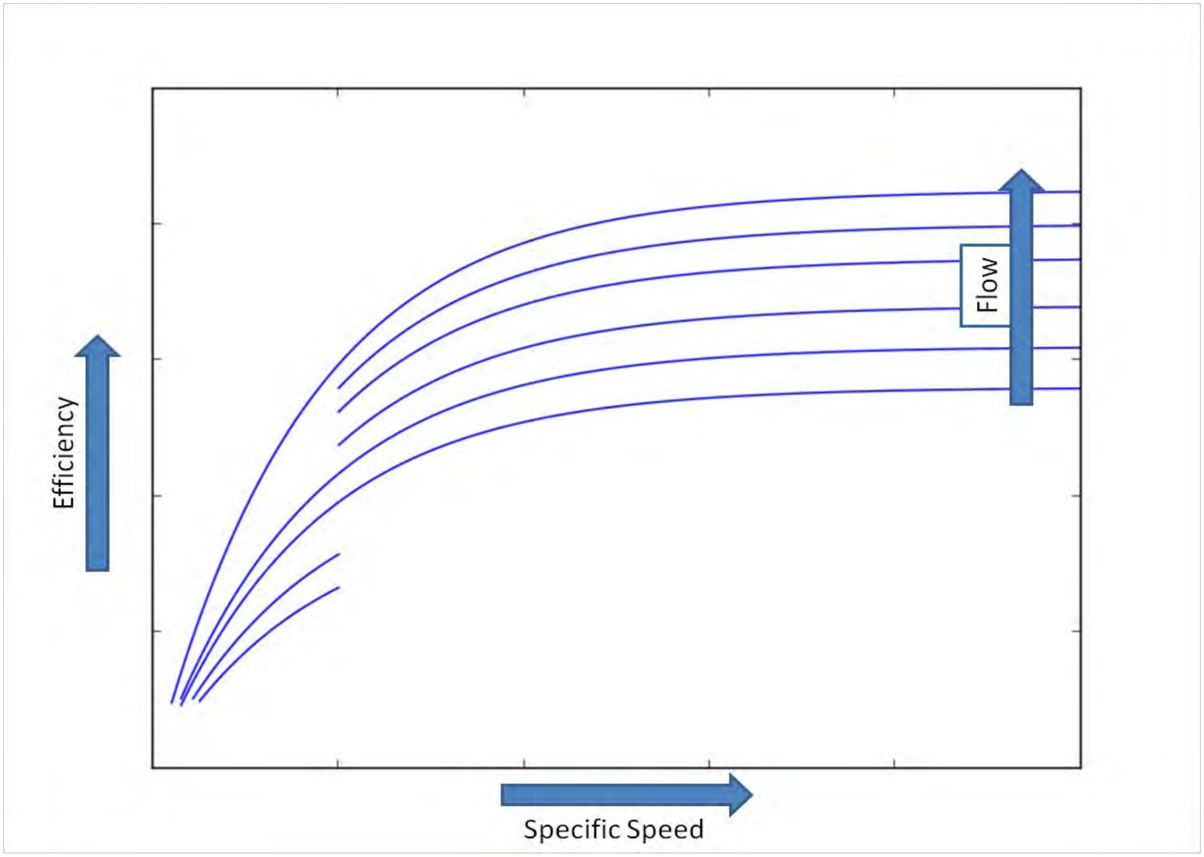

Figure 3.2 Example Graph Showing Pump Efficiency as a Function of Specific Speed and Flow

Item 3-8 DOE requests comment on whether it should consider using Reynolds number instead of flow in setting minimum efficiency standards for pumps and whether this choice would prevent adding design speed as an additional parameter. DOE notes that there are multiple methods of calculating Reynolds number for pumps and that all calculations do not produce the same relative results. As a result, DOE seeks comment on the most appropriate form of Reynolds number for pumps.

The EU's methodology relies on raising or lowering the efficiency surface based on pump speed by changing the constant in the equation. (See Equation Set 1.) DOE's preliminary analysis following the EU methodology produces a similar result to the EU, with 4-pole ESCC pumps being on average 2.2 points more efficient than 2-pole ESCC pumps for a given flow and specific speed.[30] However, DOE notes that when fitting the surfaces by allowing other parameters besides the constant to change (*i.e.,* changing the shape instead of just the vertical position as in Equation Set 2), in some areas of flow and specific speed, 2-pole is more efficient than 4-pole; in other words, the data show that the relationship is not necessarily fixed. See Appendix D for figures demonstrating these results and the related coefficients.

Equation Set 1: Vertical Change in Surface

$$\eta_{BEP\ 2-pole} = a\,(lnQ)^2 + b\,(lnQ \cdot lnNs) + c\,(lnNs)^2 + d\,lnQ + e\,lnNs + f_2$$

$$\eta_{BEP\ 4-pole} = a\,(lnQ)^2 + b\,(lnQ \cdot lnNs) + c\,(lnNs)^2 + d\,lnQ + e\,lnNs + f_4$$

Equation Set 2: Surface Shape Change

$$\eta_{BEP\ 2-pole} = a_2\,(lnQ)^2 + b_2\,(lnQ \cdot lnNs) + c_2\,(lnNs)^2 + d_2\,lnQ + e_2\,lnNs + f$$

$$\eta_{BEP\ 4-pole} = a_4\,(lnQ)^2 + b_4\,(lnQ \cdot lnNs) + c_4\,(lnNs)^2 + d_4\,lnQ + e_4\,lnNs + f$$

3.2.3.2 Impact of Setting Standards by Speed on Single Pumps Running at Multiple Speeds

The impact of pump size on efficiency has implications for any efficiency standards for single pumps offered at two or more speeds (such as Pump A and A2 in Figure 3.1). DOE understands that many manufacturers offer a given pump model at two or more design speeds, but that wet end of the pump is identical for both offerings.

Pump affinity laws indicate that a pump should have the same efficiency at any speed, and many pump manufacturers publish the same efficiency at multiple speeds. HI 14.6 notes, however, that efficiency changes are not negligible for speed changes of more than 20% [15]. The pump resources that show efficiency as a function of flow and specific speed, as indicated earlier, predict a higher efficiency for higher flow pumps at the same specific speed. Using ESCC as an example, the EU's standards show that higher flow (higher speed, or 2 pole pumps) are more efficient than lower flow pumps only for pumps less than around 800 gpm (2-pole)/400 gpm (4-pole). (See Figure 3.3.) For pumps at higher flow ranges, the EU standards require a higher efficiency for 4-pole pumps (*i.e.,* the same pump running at lower speed).

In the United States, for ESCC pumps, following the same method of fitting surfaces as is used in the EU (Equation Set 1) results in higher efficiency for 2-pole as compared to 4-pole pumps, except for at low specific speeds and high flow. (See Figure 3.3. This figure is produced by calculating $\eta_{BEP\ 2-pole}$and $\eta_{BEP\ 4-pole}$using in each equation the same specific speed, but half the flow, for the 4-pole pump as compared to the 2-pole pump.) Following the second fitting method discussed previously (Equation Set 2), the same trends apply, but the predicted differences are higher. (See Figure 3.4.) Finally, if DOE produced one surface without regard to design speed (*i.e.,* ignoring the size effect), the efficiency for a pump running at 3,550 rpm (2-pole) would always be higher than for that same pump running at 1,750 rpm (4-pole), and the

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[30] See Appendix D for a discussion of how this changes with the pump scope, *i.e.* the pumps counted as clean water.

differences would be higher than in the other possible scenarios. Table 3.9 summarizes the efficiency differences between pumps running with 2-pole and 4-pole motors for each of the scenarios discussed.

Analysis of DOE's pump performance data indicates that out of approximately 500 pairs in the ESCC database[31], 57% showed 2-pole as more efficient, 29% showed 2-pole and 4-pole equal[32], and 14% showed 4-pole more efficient than 2-pole. There do not appear to be strong trends regarding which speed is more efficient related to flow or specific speed. These data indicate much larger differences in efficiency between identical pumps running at different speeds than do the EU's standards. DOE notes that it is unknown if the published data in its database are based on testing or rather assumptions of theoretical relationships such as the affinity laws. In addition, DOE notes that a similar analysis performed on non-submersible vertical turbine pumps shows a different trend, with 77% of pairs showing 2-pole and 4-pole equal, 10% showing 2-pole more efficient, and 13% showing 4-pole more efficient (out of about 2,000 pairs); therefore, any trends identified may not hold true for all equipment classes and may simply be a function of which speeds pumps are generally optimized for in each equipment class and how much of the data is created using affinity law assumptions.

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[31] Pumps with the same manufacturer, catalog, type, model, and impeller diameter, but with different speeds, were assumed to be pairs. These pumps did not have identical specific speeds (which theoretically should be true for identical pumps), presumably because the affinity laws are not completely accurate, which would produce different calculations based on head and flow.

[32] It is unknown if, for these pumps, the manufacturers simply assumed the affinity laws, or if these are actual test results.

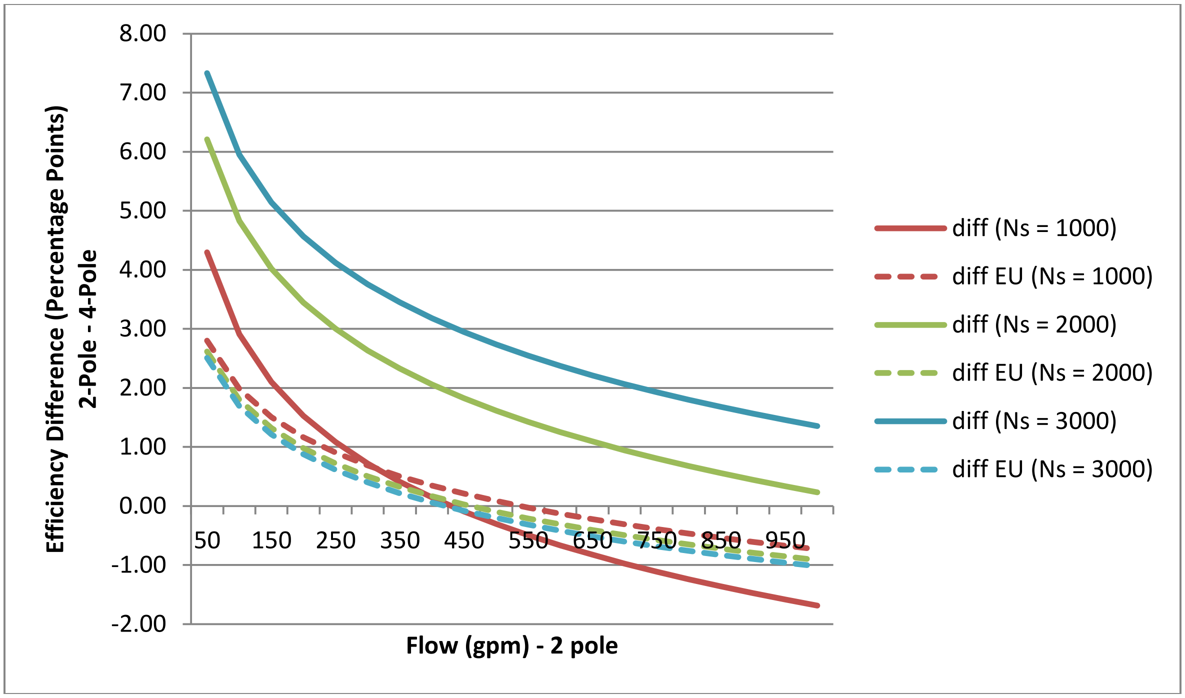

Figure 3.3 Predicted Efficiency Differences Between Single ESCC Pumps Running with 2-Pole versus 4-Pole Motors at Selected Specific Speeds (Using Equation Set 1)

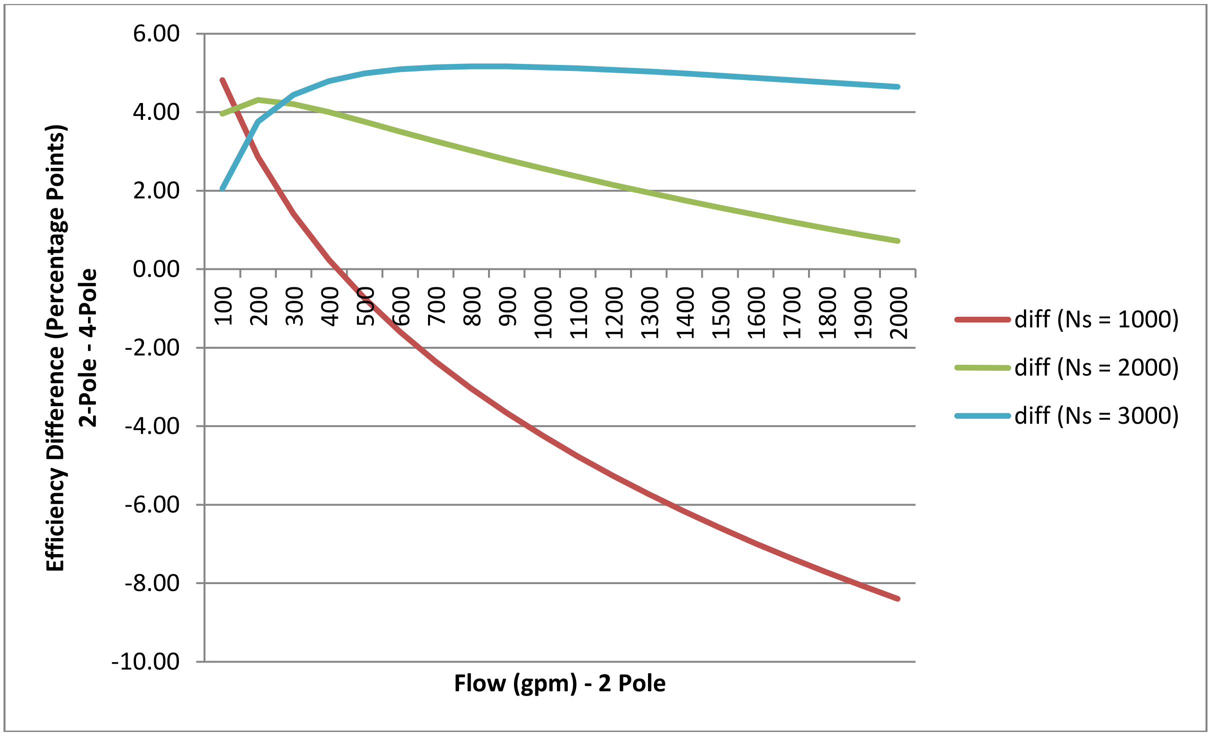

Figure 3.4 Predicted Efficiency Differences Between Single ESCC Pumps Running with 2-Pole versus 4-Pole Motors at Selected Specific Speeds (Using Equation Set 2)

Table 3.9 Comparison of Minimum Efficiencies for Identical Pumps Running at Two Different Speeds

Pump	Ns (US)	Flow (gpm) at 3,550 rpm	Flow (gpm) at 1,750 rpm	Efficiency Differences (2-pole – 4-pole) Percentage Points			
				EU (equation set 1)	DOE (equation set 1)	DOE (equation set 2)	DOE (single equation*)
A	1000	200	100	2.0%	2.9%	2.9%	5.0%
B	1000	1200	600	-0.1%	-0.7%	-5.3%	1.8%
C	2000	400	200	1.0%	3.4%	4.0%	5.6%
D	2000	1200	600	-0.4%	1.3%	2.1%	3.6%
E	3000	400	200	0.9%	4.6%	4.8%	6.7%
F	3000	2000	1000	-1.0%	1.4%	4.6%	3.8%

*In the single equation approach, DOE would not take design speed into account in developing efficiency surfaces, so a single equation would be used no matter the speed.

Item 3-9 DOE requests comment on which method of surface fitting produces the most appropriate results for both cases: (1) a smaller pump at higher speed compared to a larger pump at lower speed; and (2) identical pumps running at two different speeds. DOE requests comment on whether these relationships are expected to differ by equipment class.

3.2.3.3 DOE Options for Addressing Design Speed

If DOE does not use design speed as a feature differentiating equipment classes, it is unlikely that any pump speeds would be eliminated from the market, because only pump models with efficiencies close to the standard level would be impacted. In addition, pumps can run at multiple speeds, so a given model that might be eliminated at one speed may be able to meet the standard at a different speed. However, DOE is concerned about the implications for identical pumps offered at multiple speeds, as shown in Table 3.9. Specifically, DOE wants to make sure that it selects a method of surface fitting that produces appropriate results at all speeds.

Regardless of whether DOE sets equipment classes based on design speed, DOE must determine at what speed testing and compliance should occur. DOE may consider requiring testing and compliance with the standard based on a certain pump speed. Not all pumps are designed to operate at all speeds, particularly high speeds, however, and within a given equipment class, there will be a variation of pump speeds offered. Therefore it may be difficult for DOE to select a single speed for testing in each equipment class. In addition, some manufacturer test loops might be set up for a certain speed, so requiring testing at a different speed could increase manufacturer burden by requiring a change in test loop. Alternatively, DOE could potentially require pumps that operate at multiple speeds to meet the most stringent standard (in other words, test the same pump model at specified speeds, calculate the minimum efficiency for the pump at specified speeds, and require compliance with the greatest efficiency, if there is a difference). DOE notes that because not all pumps are designed to operate at all speeds, DOE may use manufacturer input to determine the range of speeds at which a particular pump model can be safely tested.

DOE understands that some pumps are optimized for a certain design speed (which may not be the speed at which efficiency is the highest or the speed at which DOE requires testing, and that therefore either of these approaches may penalize some pump models.

Item 3-10 DOE requests comment on the use of pump design speed as a feature that distinguishes equipment classes. In particular, DOE seeks comment on whether pumps designed for different rotating speeds perform differently enough to warrant separate equipment classes. DOE also requests comment on any physical differences between pump models offered at different speeds and the nature of those differences, including whether DOE could determine by physical inspection at what speeds a pump can safely operate.

Item 3-11 DOE requests comment on the testing and compliance burden on manufacturers under the approaches set forth above.

Item 3-12 DOE requests comment on whether it could require all pumps in a given equipment class to be tested at (a) certain speed(s) and, if so, which speed(s) is (are) most appropriate.

Item 3-13 DOE requests comment on how manufacturers in the EU are determining the minimum efficiency required for a pump offered at multiple speeds.

3.2.4 Motor (and Control) Package

As mentioned in section 1.2.3, DOE may define pumps inclusive of the motor or motor and controls. Under these scenarios, DOE would establish separate sets of equipment classes for pumps sold without motors and pumps sold with motors (or pumps sold without VSDs and pumps sold with VSDs). DOE believes that these motor (and control) packages represent a utility feature in which the pump manufacturer matches equipment to best meet customer needs.

3.2.5 Tentative Equipment Classes

Table 3.10 shows DOE's preliminary designations for pump equipment classes. These equipment classes are subject to change based on changes to the pumps for which DOE considers standards in this rulemaking, equipment definitions, additional information on the market, and information and data provided by stakeholders. For example, if DOE considers standards for pumps designed for lower nominal speeds, such as 1,200 rpm, and DOE establishes equipment classes based on pump design speed, equipment classes would also need to include pumps designed for 6-pole, 8-pole, and possibly higher motor configurations. If DOE develops a separate set of equipment classes for pumps sold with and without VSDs or with and without motors, the equipment classes would likely be identical to those shown in Table 3.10.

Table 3.10 Tentative Equipment Classes for Rotodynamic Clean Water Pumps

Pump Type	Sub-Type	Stages	DOE Terminology	Design Speed
End Suction	Close Coupled	Single	End Suction Close Coupled (ESCC)	3,500
				1,750
	Own Bearings/ Frame Mounted	Single	End Suction Frame Mounted (ESFM)	3,500
				1,750
In-Line		Single	In-Line (IL)	3,500
				1,750
Axial Split		Single	Double Suction (DS)	3,500
				1,750
		Multi	Axially Split Multi-Stage (AS)	3,500
				1,750
Radial Split		Multi	Radially Split Multi-Stage (RS)	3,500
				1,750
Vertical Turbine	Non-Submersible	Any	Vertical Turbine (VT)	3,500
				1,750
	Submersible	Any	Submersible (VT-S)	3,500
				1,750
Axial/Propeller and Mixed Flow		Any	Axial/Propeller and Mixed (A-M)	3,500
				1,750

3.3 Technology Assessment

The technology assessment focuses on understanding how energy is used by commercial and industrial pumps and what potential technology changes to the design and construction of these pumps would improve their energy efficiency. Measures that improve the energy efficiency of the equipment are called “technology options.” These measures are based on existing technologies, as well as working prototypes. In consultation with interested parties, DOE will develop a list of technology options to consider in this rulemaking. Initially, this list will include all those options that may improve energy efficiency, including a max-tech design. Then DOE will consider each of these technology options against four screening criteria, as discussed in section 4. Technology options that pass all the screening criteria are called “design options” and are analyzed in the engineering analysis (section 5).

To develop the list of technology options that could improve the efficiency of the pumps for which DOE is considering energy conservation standards in this rulemaking, DOE is reviewing manufacturer catalogs, recent trade publications, and technical journals. DOE also intends to consult with interested parties to gather information on pump designs and applications.

Pump efficiency can be increased by improving the technology used in the design and manufacturing process. Based on its preliminary review, DOE identified the following technology options as having potential to improve the efficiency of pumps:

1. improving the hydraulic design,

2. smoothing surface finish,
3. reducing running clearances,
4. reducing mechanical friction in seals,
5. reducing other volumetric losses,
6. using a variable speed drive,
7. improving VSD efficiency, and
8. reducing VSD standby and off mode power usage.

Each technology option affects one or more sources of efficiency losses in pumps (leakage losses, disk friction, and hydraulic losses). Some of these losses are dependent on specific speed; therefore, the effect on efficiency of these design options will be dependent on specific speed.

Note that technology options 6, 7, and 8 would not be considered in regulatory option 1; they would only be considered if DOE defines pumps inclusive of the motor or motor and controls.

3.3.1 Improving Hydraulic Design

This option involves modification of the impeller and volute or diffuser designs to improve the efficiency of the pump at the BEP by controlling the diffusion process and reducing recirculation in the pump and by widening the efficiency curve, so that efficiency does not drop off as quickly as the pump moves away from its BEP. This option has the potential to improve efficiency of pumps being sold today by as much as 10-12%, depending on the size and specific speed of the pump and on how poor the pump performance was before design modifications.

DOE recognizes that some designs, while less efficient, may be necessary for certain applications. For example, enclosed impellers (with side walls) are normally expected to be more efficient than open impellers (without side walls). However, open impellers may be necessary, even in clean water applications. For example, many vertical turbines employ open impellers, because of the possibility that sand may enter the pump through the well. DOE will take into account these issues, including the possibility of market shift as a result of efficiency levels that may require certain impeller types, when developing technology options. DOE requests any information that would help characterize these issues.

3.3.2 Smoothing Surface Finish

Impellers can be polished by spinning them in a slurry, and volutes and diffusers can be polished by similar methods, or may be coated with enamel or other coatings to improve surface finish. Research shows that smoothing the entire pump can create theoretical efficiency gains on the order of 18 percent, but this can be prohibitively expensive [21]. Smoothing certain sections of the pump has the potential to increase pump efficiency by an estimated 1-3% overall.

3.3.3 Reducing Running Clearances

There are a number of running clearances that might be tightened, which would reduce the amount of volumetric losses that occurs as pressurized liquid leaks across the running clearance to a zone of lower pressure. The running clearances to be considered for tightening include:

- front wear rings,
- back wear rings (thrust balance rings),
- center bushing or wear ring on multi-stage axial split pumps with crossover, and
- balance drums or sleeves.

To further tighten these clearances beyond what manufacturers have already done might require alternate materials for wear rings and other running surfaces, tighter machining tolerances, modifications to assembly procedures, or some combination of these adaptations. These changes could improve pump efficiency by up to 3% depending on specific speed.

3.3.4 Reducing Mechanical Friction in Seals

There may be different seal materials or seal designs (e.g., non-contacting gas seals) that produce less mechanical friction loss, which will result in improved efficiency. These improvements will be possible mainly in higher pressure pumps. These improvements are not expected to improve efficiency by more than one percent.

3.3.5 Reducing Other Volumetric Losses

This might involve design changes to eliminate or reduce the volumetric losses in open impeller settings, thrust balance holes, and seal flush systems. Design changes in these components have the potential to increase pump efficiency by an estimated 1-3%.

3.3.6 Using a Variable Speed Drive

As discussed in section 1.2.3, for pumps in variable load applications, variable speed drives can be used to adjust pump output without throttling or bypass. This results in reduced power draw and maintenance of efficiency. (See section 1.2.3.) However, at full load, overall efficiency is lower, due to the losses within the VSD. VSDs will be considered a technology option in regulatory option 3. In addition, use of a VSD may introduce energy use in standby and off modes. DOE will consider this energy use in analyzing VSD use as a technology option.

3.3.7 Improving VSD Efficiency

VSDs have varying degrees of efficiency, and improvements to VSD efficiency will be considered a technology option for pumps sold with motors and VSDs.

3.3.8 Reducing VSD Standby and Off Mode Power Usage

Technology options may be considered that reduce the energy use of a VSD in standby and off modes.

Item 3-14 DOE welcomes comment on the technology options identified in this section, including further details on methods (such as lists of specific methods for each listed broad option) and potential efficiency gains, as well as information on whether the method in question is applicable to all pumps in a given equipment class or only pumps with certain design characteristics). DOE also welcomes comment on whether there are other technology options that it should also consider.

Item 3-15 DOE welcomes comment on the relevance of the technology options identified to pumps sold with smaller impellers than the full impeller on which DOE is tentatively proposing to base a standard. In particular, would these design options be carried through to pumps with all impeller sizes?

Item 3-16 DOE requests information related to various impeller types used in clean water pump designs and the efficiency impacts of each type.

4. SCREENING ANALYSIS

The purpose of the screening analysis is to screen out technology options that DOE will not consider in its potential energy conservation standard rulemaking for commercial and industrial pumps. At the outset, DOE develops a list of technology options for consideration through its own research and in consultation with interested parties. Development of the list is based on the technologies described in section 3.3. The identified candidate technology options encompass all those technologies that may improve energy efficiency.

DOE then reviews each technology option considering the following four criteria, as provided in sections 4(a)(4) and 5(b) of *Procedures, Interpretations, and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products* (see 10 CFR Part 430, Subpart C, Appendix A):

1. *Technological feasibility.* DOE does not further consider technologies that are not incorporated in commercially available equipment or in working prototypes.

2. *Practicability to manufacture, install, and service.* If DOE determines that mass production of a technology in commercial equipment and reliable installation and servicing of the technology could not be achieved on the scale necessary to serve the relevant market by the time of the effective date of the standard, then it does not consider that technology further.

3. *Adverse impacts on product or equipment utility or availability.* If DOE determines that a technology will have a significant adverse impact on the utility of the equipment to significant subgroups of consumers, or result in the unavailability of any covered equipment type with performance characteristics (including reliability), features, size, capacities, and volumes that are substantially the same as equipment generally available in the United States at the time, it does not consider that technology further.

4. *Adverse impacts on health or safety.* If DOE determines that a technology will have significant adverse impacts on health or safety, it does not consider that technology further.

DOE will fully document the reasons for eliminating any technology options during the screening analysis and solicit stakeholder comment. The remaining options, called design options, are considered further in the engineering analysis (section 5).

Item 4-1 Are there any technologies listed in section 3.3 (or others not proposed) that DOE should not consider because of any of the four screening criteria? If so, which screening criteria apply to the cited technology or technologies?

5. ENGINEERING ANALYSIS

After conducting the screening analysis described above, DOE performs an engineering analysis based on the remaining design options that would improve pump efficiency. This section provides an overview of the engineering analysis and discusses baseline units, DOE's proposed approach for determining the cost-efficiency relationship, proprietary designs, efficiency levels, and cumulative regulatory burdens that might affect the engineering analysis.

5.1 Overview

The purpose of the engineering analysis is to determine the relationship between manufacturer selling price (MSP) and efficiency for pumps. In determining the cost-efficiency relationship, DOE estimates the increase in manufacturer selling price associated with design changes that increase the efficiency of pumps relative to the baseline models (which in most cases are the most typical low efficiency equipment currently sold on the market).

As a preliminary step in this analysis, DOE may determine an appropriate subset of representative equipment classes to analyze. DOE would extrapolate the results of this analysis to the remaining equipment classes. Typically, each representative equipment class would represent the majority of the shipments in its category. The number of representative equipment classes will depend on the availability of data that would allow for developing appropriate relationships between the engineering analysis results of the representative equipment class and the other equipment classes not directly analyzed.

For each representative equipment class, DOE may analyze a subset of representative units at selected flow and specific speed. Once DOE has identified cost-efficiency relationships for the representative units, it will scale the engineering analysis results to cover the full range of flow and specific speeds. DOE proposes to develop scaling relationships for pumps by creating a model that describes efficiency as a function of a pump's flow and specific speed at BEP. As discussed in Section 1.4.5, DOE has developed a method to create the full range of surfaces from manufacturer catalog data. DOE may develop additional intermediate surfaces with these same data to use for scaling. Alternatively, DOE could use the EU surfaces for scaling. Finally, DOE could use the representative units to create incremental cost increases and efficiency increases, and apply these directly to other models.

Once DOE establishes the representative equipment classes and representative units, it selects a baseline model as a reference point for each representative unit from which to measure changes resulting from the design options. DOE will then develop separate cost efficiency relationships for each baseline model analyzed. DOE intends to use pump teardowns and efficiency tests to develop these cost-efficiency relationships. DOE is considering the appropriate test procedures and will conduct a separate test procedure rulemaking (section 1.5).

To develop the relationships between efficiency and technology options, DOE intends to utilize publicly available data from manufacturer catalogs and websites, where the technology options used can be identified. DOE encourages interested parties to submit test data that will improve DOE's understanding of pump performance. Using these data, which will allow DOE to determine the incremental costs of changes in material, labor, shipping, and overhead from the baseline, DOE will develop cost estimates for design options (which it will also use in the manufacturer impact analysis, section 12).

Item 5-1 DOE seeks input on the methods and approaches used by manufacturers to improve the efficiency of pumps and, in particular, how frequently hydraulic re-design would be the only method employed.

Item 5-2 DOE welcomes comment from interested parties on the best methodology for scaling cost-efficiency curve results from the representative units to the representative equipment classes and extrapolating from the representative equipment classes to the remaining equipment classes not directly analyzed.

5.2 Representative Class Selection

Not all equipment classes may require unique representative units. For example, many manufacturers publish identical performance data for End Suction Close Coupled (ESCC) and End Suction Frame Mounted (ESFM) pumps. These are essentially identical pumps, but are supplied with different motors, which should affect wire-to-water efficiency but not pump efficiency. Ideally, ESFM pumps would be the preferred pump type to test in terms of accuracy of pump efficiency measurement, although ESCC pumps represent significantly more shipments. If DOE defines pumps inclusive of the motor and/or motor and controls, it will be necessary to test ESCC pumps in addition to ESFM pumps.

Other equipment classes that could potentially be served by only one representative unit are vertical turbine and submersible vertical turbine pumps, as the bowls used in these pumps are often identical. However, the metric for submersible turbines may be overall efficiency, which would be different from the metric for vertical turbines.

Item 5-3 DOE seeks comment on its selection of representative classes: which classes could be grouped together for this analysis, and which class should be tested.

5.3 Representative Unit Selection

Ideally, selection of representative units within an equipment class is based on identification of units that are functionally equivalent in all respects except efficiency. For many products, this would be done by choosing equipment of the same size at both baseline and higher efficiency levels (*i.e.,* standard and premium efficiency motors) from a single manufacturer. An additional representative unit at a different size may also be chosen depending on the size range of the equipment class. For pumps, however, a given pump manufacturer generally does not offer multiple pumps with the same BEP at full impeller diameter. This is because manufacturers strategically offer pumps with overlapping and distributed performance ranges (at full and reduced impellers) to cover a large range of potential operating conditions. In addition, pump equipment classes currently under consideration cover a wide and continuous range of variations including designs (specific speed) and sizes (flow). If DOE defines minimum efficiency as a function of specific speed and flow, representative unit selection would need to account for specific speed in addition to size.

DOE must select representative units for which there are pump models on the market at approximately constant BEP flow and specific speed but with different efficiency levels, and DOE would have to examine representative units at many flow and specific speed combinations. To identify these units, DOE developed a computer program to look at its database and iterate ranges of flow and specific speed to achieve bins of three pumps with as wide an efficiency range as possible. The parameters of the program can be altered to attempt to find pumps at desired baseline and higher efficiency levels, as discussed below.

DOE realizes that it may be difficult to identify pump models with similar flow and specific speed at BEP that are available at both baseline efficiency and increased efficiency levels. In this case, DOE will consider scaling relationships to adjust testing results and develop cost-efficiency relationships using equipment with different BEPs.

Item 5-4 DOE welcomes comment on the selection of representative units in terms of appropriate flow and specific speed ratings within each equipment class.

5.4 Baseline Models

DOE selects baseline models that represent the characteristics of pumps in a given equipment class used in common commercial or industrial applications. Typically, the baseline model would be a model that just meets current energy conservation standards. Because energy conservation standards for pumps do not exist, however, DOE will select baseline models representative of the least efficient, most typical pump offered for sale in the market. Selection of the baseline model for each representative unit will encompass consideration of pump features and performance characteristics.

DOE is considering the appropriate method to develop baseline efficiency levels representative of the least efficient, most typical pumps offered for sale in each equipment class, recognizing that each equipment class contains pumps with a broad range of flows and specific speeds. As an example, the bottom-of-market surface presented in Figure 1.4 (in section 1.4.5) was developed to capture the least efficient pumps at any flow and specific speed. However, this approach results in areas of flow and specific speed without any pumps near this level (as can be seen in Figure 5.1). DOE could address this issue through disaggregation into additional equipment classes and development of a discontinuous function for the baseline level. Alternatively, DOE is considering a baseline level that covers many pumps over a wide range of flow and specific speed, such as that shown in Figure 5.1, in comparison to the bottom-of-market example. More figures can be found in Appendix C.

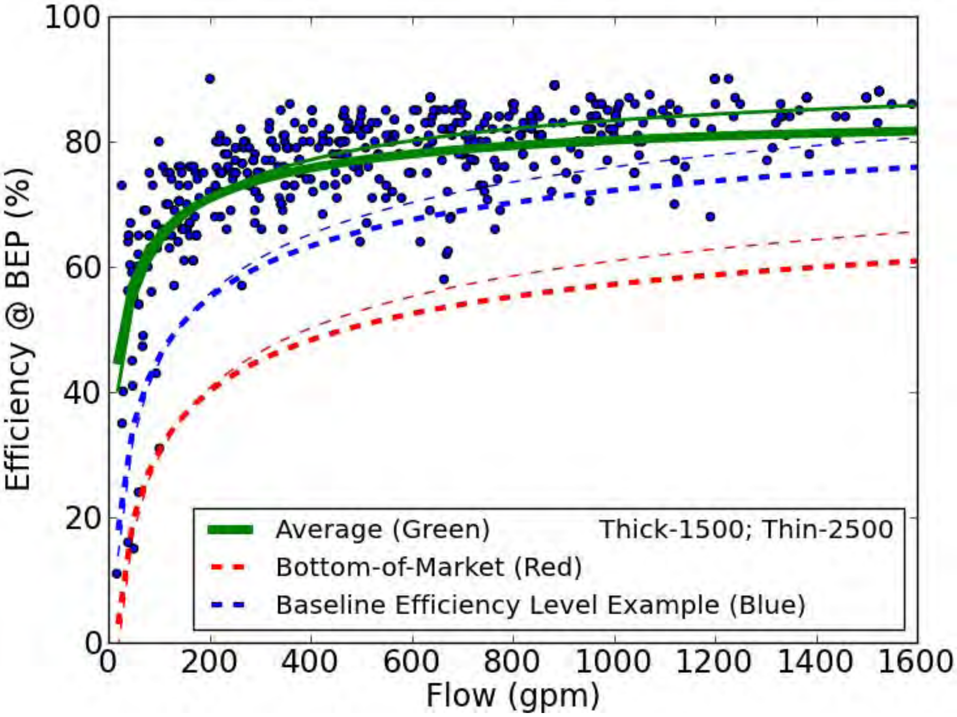

Figure 5.1 Example Baseline Efficiency Levels for ESCC Pumps (Ns=1500-2500)

DOE's determination of the appropriate baseline efficiency levels will be determined by pump model data, pricing data, and shipment data by efficiency that are publically available or provided to DOE. Shipment data may indicate more appropriate baseline levels than model availability data, as the least efficient pumps may not have significant shipments and therefore would not be considered the least efficient, most typical pumps in the market.

Item 5-5 DOE seeks comment on the selection and performance characteristics of baseline models for each equipment class. DOE will consider such comments in defining the characteristics of the proposed baseline models.

5.5 Efficiency Levels

To establish the efficiency levels DOE intends to consider, DOE will identify the highest efficiency that is technologically feasible within each equipment class (*i.e.*, the max-tech level) and analyze the design options and costs associated with improving pump efficiency from the baseline through the max-tech model. DOE intends to collect pump efficiency data from various manufacturer catalogs to establish the range of efficiencies currently available on the market. DOE will also use these data to categorize relationships between efficiency and technological options where the technological options used can be identified.

When defining a max-tech level based on market maximums, DOE found that a surface developed to go through the very highest efficiency pumps (as shown in Figure 1.4 in section 1.4.5) will not represent the maximum efficiency available on the market for the majority of the flow-specific speeds. If a representative unit is selected at a market-max level that does not exist for many flow-specific speeds, it may not be appropriate to apply the results of the cost curve to pumps at these flow-specific speeds; in other words, the efficiency level may not represent the same level of cost-effectiveness at other flow-specific speed combinations.

As in the baseline efficiency level discussion, DOE could address this issue through disaggregation into additional equipment classes and development of a discontinuous function for the market-max level. However, the cost of achieving the levels would not be discontinuous; the lack of models in certain areas likely just represents the lack of a market. Alternatively, DOE could draw a market-max level that goes through many pumps at a wide range of flow-specific speeds. Figure 5.2 shows an example of this latter option, in comparison to the top-of-market surface shown in Figure 1.4 Additional figures can be found in Appendix C.

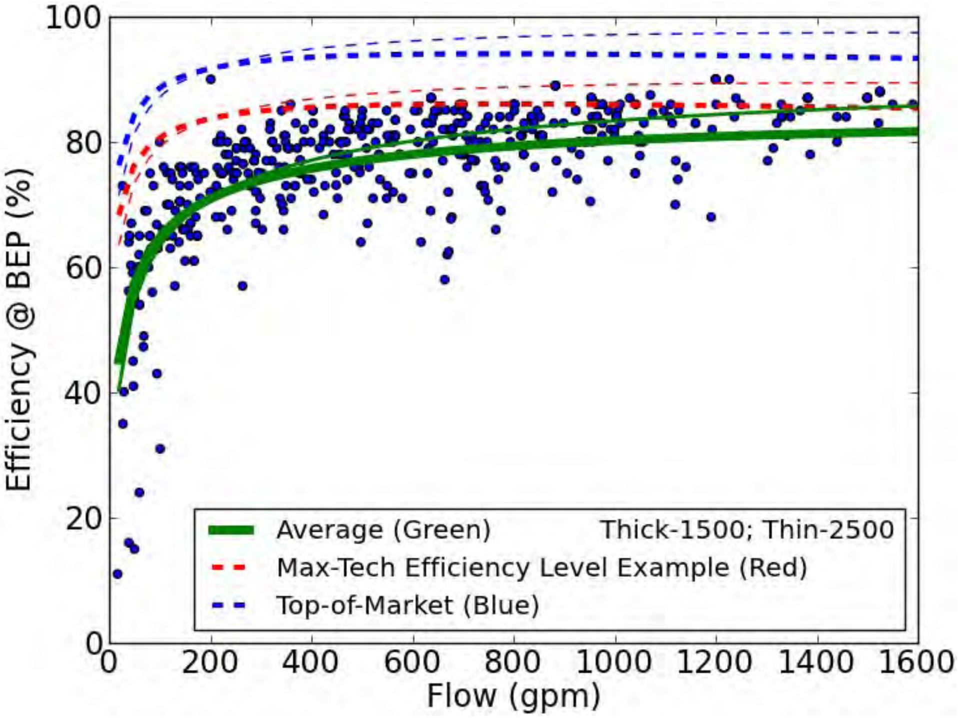

Figure 5.2 Example Max-Tech Efficiency Levels for ESCC Pumps (Ns=1500-2500)

DOE notes that the maximum efficiency levels available in current pump equipment may not necessarily correspond to the max-tech levels. It is possible that some of the design options that have met the screening criteria (*i.e.*, passed the screening analysis) may be working prototypes that are not yet commercially available and, therefore, would not be found in today's available maximum efficiency pumps. DOE seeks stakeholder input to determine appropriate max-tech efficiency levels. (42 U.S.C. § 6295(p)(2))

Item 5-6 DOE seeks input from stakeholders regarding the range of efficiency levels that should be examined as part of its analysis.

Item 5-7 DOE seeks input from interested parties on a methodology that would be appropriate for determining the max-tech models for each pump analyzed.

5.6 Developing Cost-Efficiency Relationships

DOE uses a manufacturing costs structure that follows the traditional manufacturing process and includes:

1) Equipment Costs (MSP): Recurring costs associated with manufacturing.

    a. Full production cost (manufacturer production cost (MPC)), *i.e.,* direct labor, direct material, overhead (indirect labor, indirect material, maintenance, depreciation, taxes, insurance related to assets).

    b. Non-production cost, i.e., selling (market research, advertizing, point-of-sale (POS) promotion, sales person compensation and travel, logistics such as warehousing, delivery, record keeping), general and administration (costs for service and staff units, general corporate costs such as compensation, etc.), research and development (R&D) (costs associated with efforts to find new or improved products or production processes) and interest (costs of borrowing funds). DOE typically uses manufacturer markups calculated from publicly available financial information (*e.g.*, Securities and Exchange Commission 10-K reports) to account for non-production costs.

2) Conversion Costs: Investments to bring production facilities and equipment designs in compliance with the new regulation.

    a. Equipment conversion costs, *i.e.,* investments in research, development, testing, and marketing focused on making equipment designs comply with the new standard.

    b. Capital conversion costs, *i.e.,* investments in property, plant, and equipment to adapt or change existing production facilities so that the new equipment designs can be fabricated and assembled.

    c. Stranded assets, *i.e.,* equipment or tooling that become obsolete as a result of new regulation.

To derive the material and labor cost portions of the full production cost, DOE plans to purchase, test, and tear down selected pumps within each representative equipment class. DOE will disassemble and inventory the pump components, creating a bill of materials and identifying manufacturing processes required to fabricate the pumps.

DOE may supplement the findings from its tests and teardowns through: (1) a review of data collected from manufacturers about prices, efficiencies, and other features of various models of pumps, and (2) interviews with manufacturers about the techniques and associated costs used to improve efficiency. If possible, DOE will then aggregate the cost numbers by weighing individual data points by company-level sales volumes for each equipment class.

DOE recognizes that there may be limited public information on national shipments, manufacturing costs, channels of distribution, and manufacturers' market shares of pumps. DOE encourages interested parties to submit any available data that pertain to these areas of interest and that would improve DOE's understanding of the pump market.

DOE is sensitive to manufacturer concerns regarding proprietary designs and will make provisions to maintain the confidentiality of proprietary data submitted by manufacturers or discussed during manufacturer interviews. Materials provided to Lawrence Berkeley National Laboratory (LBNL) and Navigant Consulting, Inc. (NCI), DOE contractors for this rulemaking, are generally subject to the terms of the applicable agreement under which those materials are submitted. In the case of materials provided to LBNL or NCI in the context of a DOE rulemaking and subject to a non-disclosure agreement, those materials are generally not shared with DOE, apart from aggregated data that do not identify particular submitters. These materials may also be subject to a variety of laws and regulations governing the disclosure of Federal agency information. Information submitted to DOE will be protected in accordance with all applicable federal laws, rules, or regulations, including but not limited to the Trade Secrets Act, 18 U.S.C. §1905, and the Freedom of Information Act (FOIA), 5 U.S.C. §552, and DOE's implementing regulations at 10 CFR 1004.

Manufacturer cost information should reflect the variability in baseline models, design strategies, and cost structures that exist among manufacturers. If necessary, DOE will qualify any aggregated cost-efficiency data using information obtained through follow-up discussions with manufacturers. These interviews will provide a deeper understanding of the various combinations of technologies used to increase pump efficiency, as well as their associated manufacturing costs.

During the interviews with manufacturers, DOE will gather information about the capital expenditures needed to increase the efficiency of baseline models to various efficiency levels (*i.e.*, conversion expenditures by efficiency). DOE will also gather information about the depreciation method(s) used to expense the conversion expenditures. DOE will then estimate the contribution of the depreciation of conversion capital expenditures to the incremental overhead portion of the full production cost.

This proposed approach will enable DOE to characterize the cost-efficiency relationship for pumps across the entire efficiency range for all equipment classes and allow the public to examine the aggregated cost and design assumptions that underlie the cost-efficiency estimates, while maintaining the confidentiality of proprietary data as described above.

DOE typically uses markups to represent non-production costs and convert the MPC to the MSP. DOE intends to estimate manufacturer markups from publicly available financial information (*e.g.*, Securities and Exchange Commission 10-K reports) and from information obtained in manufacturer interviews.

DOE typically does not include conversion costs in the engineering analysis. Although these costs may be passed along to the customer, they are traditionally considered during the manufacturer impact analysis. DOE understands, however, that one of the primary methods used to increase the efficiency of pumps is hydraulic re-design, which may not represent any difference in manufacturing cost, but which incurs primarily up-front R&D and conversion costs (including the complete remaking of pattern tooling, new machine drawings, a full range of hydraulic testing to document the new hydraulic performance, and manufacturing plant conversion). If DOE decides to account for some or all of these conversion costs, these costs would be included as part of the manufacturer markups (see section 6).

Item 5-8 For each equipment class, DOE welcomes comments on methods and approaches that DOE intends to employ to determine potential efficiency improvements for pumps. Detailed information on the pump performance and the incremental manufacturing costs (e.g., material costs, labor costs, overhead costs, building conversion capital expenditures, capital expenditures for tooling or equipment conversion associated with more efficient designs, R&D expenses, and marketing expenses) would be useful.

Item 5-9 DOE welcomes comment on the markup approach proposed for developing estimates of manufacturer selling prices.

Item 5-10 DOE welcomes comment on the approach to determining the relationship between manufacturer selling price and pump efficiency.

Item 5-11 DOE welcomes comment on the conversion costs required to improve the efficiency of the pumps to various levels, as well as what portion of these costs would be passed on to the consumer.

5.7 Proprietary Designs

DOE will consider in its engineering and economic analyses all design options that are commercially available or present in a working prototype, including proprietary designs and technologies. However, DOE will consider a proprietary design in the subsequent analyses only if the achieved efficiency level can also be reached using other non-proprietary design options. If the proprietary design is the only approach available to achieve a given efficiency level, then DOE will reject that efficiency level, as the analytical results would appear to favor one manufacturer over others. DOE welcomes comment on whether there are proprietary designs it should be aware of that may give some manufacturers a disproportionate advantage for any of the pump designs under consideration in this rulemaking.

5.8 Outside Regulatory Changes Affecting the Engineering Analysis

In conducting an engineering analysis, DOE takes into consideration the effects of other DOE energy conservation standards and regulatory changes outside DOE's statutory energy conservation standards rulemaking process that can impact the manufacturers of the covered equipment. Some regulatory changes can also affect the efficiency or energy consumption of the pumps covered under this rulemaking. DOE will attempt to identify all such outside engineering issues that could impact the engineering analysis. The consideration of these issues is closely related to the cumulative regulatory burden assessment that DOE will carry out as part of the manufacturer impact analysis (see section 12.5).

Item 5-12 DOE welcomes comment on whether there are outside regulatory changes that DOE should consider in its engineering analysis of pumps.

6. MARKUPS ANALYSIS

DOE uses manufacturer-to-consumer markups to convert the MSP estimates from the engineering analysis to consumer prices, which are then used in the LCC and PBP analyses. End-user prices are needed for the baseline efficiency level and all other efficiency levels under consideration to estimate consumer costs and benefits as a result of energy conservation standards. DOE will obtain these end-user prices by applying manufacturer-to-consumer markups (consisting of distribution channel markups and sales tax) to the MSP estimates.

To develop estimates for markups, DOE must identify distribution channels (*i.e.*, how the equipment is distributed from the manufacturer to the consumer). Once it determines the distribution channels used for each of the equipment classes, DOE will rely primarily on economic census data from the U.S. Census Bureau and input from the industry to estimate how equipment is marked up in the distribution chain from the manufacturer to the consumer. DOE may also consider whether end-user price data can be used to characterize overall manufacturer-to-consumer markups.

The following subsections summarize DOE's approach for developing markups for the Preliminary Analysis of commercial and industrial pumps.

6.1 Market Participants and Distribution Channels

DOE's review of information indicates that pump manufacturers provide pumps to the marketplace through a variety of channels.

Figure 6.1 shows the likely distribution channels for commercial and industrial pumps. In the original equipment manufacturer (OEM) and direct-to-customer channels, DOE expects that the manufacturer sells the equipment directly to the OEM, or customer, through a national account. For the OEM channel, after the OEM integrates the pump(s) into a final packaged product, it is expected that the OEM distributor sells the packaged unit to the customer. In the wholesaler channels, DOE believes that the manufacturer sells the equipment to a wholesaler, who in turn may sell it directly to the customer or through a contractor.

Manufacturer → Customer	(Direct End-User Channel)
Manufacturer → OEM → OEM Distributor → Customer	(OEM Channel)
Manufacturer → Wholesaler → Customer	(Distributor Channel)
Manufacturer → Wholesaler → Contractor → Customer	(Contractor Channel)

Figure 6.1 Commercial and Industrial Pump Distribution Channels

DOE has preliminarily identified the following high-volume application segments [22] for commercial and industrial water pumps: agriculture; water and sewage handling; construction; heating, ventilating, and air conditioning (HVAC); food processing, pharmaceutical; refineries; and hydropower. DOE believes these application segments map to market segments for which the applicable distribution channels are those discussed previously. For the OEM channel, where pumps are integrated in the systems manufactured by the OEMs, DOE's preliminary review suggests the products are sold only into the commercial and industrial market segments.

Item 6-1 DOE requests information on the distribution channels under consideration.

Item 6-2 DOE requests comments and additional information on the appropriate way to establish distribution channel percentages across equipment classes and application (market) segments for the current rulemaking. In particular, DOE seeks information on the percentage by market segment (i.e., agriculture, municipal, commercial, industrial, and other markets) of direct sales, OEM sales, wholesaler to customer sales, wholesaler to contractor sales, and other sales. DOE seeks this information over the total market.

6.2 Estimating Markups

DOE intends to develop baseline and incremental markups for commercial and industrial pumps. Baseline markups are cost multipliers applied to the MSP of baseline equipment, while the incremental markups are cost multipliers applied to the incremental cost change in the MSP of the higher efficiency equipment. The markup analysis will generate end-user prices for each equipment efficiency level that DOE considers.

DOE plans on using data sources such as the U.S. Census Bureau Economic reports, trade association member aggregate profit analysis reports, as available, and RS Means mechanical cost data to estimate baseline and incremental markups. For the sales through the direct end-user channel, DOE will estimate the markup percentage based on information provided by the manufacturers on differences in the final end-user price through the distribution channels and the manufacturer-to-wholesaler prices. For the OEM channel, DOE will first estimate the manufacturers' markup percentage using either public domain data from a representative sample of manufacturers or economic census data from the U.S. Census Bureau for the specific industry group. Then, the distributors' mark-up multiplier for the OEM equipment incorporating the pumps will be estimated using the wholesaler markup. For estimating wholesaler markups, DOE will use the U.S. Census Bureau Economic Census reports and the aggregate profit analysis reports. For estimating general contractor markups, DOE proposes to use the U.S. Census Bureau data for Pumps and Pumping Equipment Manufacturing (North American Industry Classification System 333911) and RS Means mechanical cost data. For the appropriate sales tax markup, population-weighted average tax data will be based on the Sales Tax Clearinghouse and U.S. Census Bureau. DOE may consider adding shipping costs to the markups or include them in the manufacturer's sales price, as appropriate.

Item 6-3 DOE seeks comment on other sources of relevant data that could be used to characterize markups for commercial and industrial pumps.

Item 6-4 DOE requests feedback on its proposal to use incremental distribution channel markups.

Item 6-5 DOE seeks comment on appropriate transportation and shipping costs to include in the analysis and whether those costs are likely to vary for higher efficiency commercial and industrial pumps.

7. ENERGY USE AND END-USE DUTY PROFILE ANALYSIS

The purpose of the energy-use and end-use duty profile analysis is to identify how equipment is used by end users, and to determine the energy savings potential of equipment with a more efficient design in the same operating conditions. The results of this analysis are used as input to the LCC, PBP, NIA, and other downstream analyses.

7.1 Overview

The annual energy consumption (AEC) associated with a pump in actual use conditions depends primarily on the power drawn by the pump and its duty profile. DOE uses the term "duty profile" to represent the variation of the pump flow rate and head at the point of pump outlet over the usage cycle in a specific time frame (annual, monthly, and daily), relative to a predetermined fixed duty or operating point on the pump performance curve. The duty or operating point may correspond to the "design" or "peak flow rate", or other well defined operating point on the pump performance curve. Flow rate and head are related through the pump performance curve. As flow rate is the more commonly used descriptor of the pump output, DOE will use duty profile to represent the variability of the ratio of the actual flow rate to a predetermined fixed flow rate over the typical usage period for pumps with fixed speed drives. Pumps coupled to VSDs follow the system curve of the network connected to the pump. In this case, the duty profile will represent the distribution of the operating hours within a range near a selected point on the system curve from the minimum turndown flow rate to the maximum allowable flow rate of the system.

For most pumps, the end-use duty profiles are expected to vary across the equipment classes and application segments. If there is little variation in the pump flow rate over the period of use, only the number of annual operating hours needs to be determined to estimate the AEC. For an application driven by a VSD, the flow rate will change continuously based on the pumping load. In this case, the AEC is determined by a summation of the number of hours run for each specific flow rate and pump head bin on the system curve and the corresponding hourly energy consumption in each bin.

A pump's specified operating point efficiency in relation to the pump's efficiency at BEP is used in determining the AEC of a pump under actual usage condition. Ideally the user will size the pump such that the BEP of the pump closely matches the most frequent duty requirement of the pumping load. However, pump manufacturers produce only a limited range of pumps in a given series to meet a wide range of duties encountered in typical operating conditions. This creates the situation of catalog inefficiency, where the user purchases the pump closest to, but not necessarily at, the specified duty point. This catalog inefficiency results in deviation of the operating point of the selected pump from its recommended BEP. DOE recognizes that the manufacture and use of discrete sizes of pumps, limitation of the range of available sizes, and practical application constraints result in pumps not operating at the manufacturer recommended BEPs. DOE also recognizes that pumps are often designed to exceed the flow rate capacity and head requirements as an engineering precaution. In addition, pumps are often selected based on the peak load or maximum system capacity, resulting in further inefficiency. These considerations apply to both the baseline pump energy use and to the energy use of more efficient pumps.

DOE will develop statistical models describing the expected range of duty profiles for pumps in different applications. DOE will determine whether the model parameters should also vary with the pump equipment class or capacity. DOE will use manufacturer pump curves and pump similarity laws to determine the energy use of a pump under the expected deviation from the BEP. This approach will provide a statistical distribution of AEC values for each pump type and application, for use in the LCC and PBP analysis (section 10).

Item 7-1 DOE requests input and recommendations for identifying high sales volume and large installed base application segments corresponding to specific applications for which the pumps used may have similar duty profiles.

Item 7-2 DOE welcomes recommendations on sources of data or analysis methods that would provide end-use duty profiles for each of the equipment classes of pumps covered under this rulemaking in the major application segments.

Item 7-3 DOE requests input on ways to characterize pump sizing and selection practices for different equipment classes and applications.

Item 7-4 DOE requests comment on the degree of oversizing prevalent in different application segments.

Item 7-5 DOE welcomes comment on methods for determining nominal (non-market segment specific) duty profiles for pump equipment classes considered in this rulemaking.

Item 7-6 DOE welcomes comment on the current penetration level of VSDs in the installed base of equipment in each application segment for each of the equipment classes considered in this rulemaking. DOE also welcomes comment on the baseline condition for applications without VSDs, such as running at full load, use of a throttling valve, etc.

7.2 Analytical Approach

DOE will estimate the energy savings for an equipment class based on the calculated energy saving potential for improved efficiency designs for each representative unit. For each analyzed representative unit, the starting point for the AEC calculation will be the power curves developed in the engineering analysis for a range of operating points on the pump performance curve. DOE will estimate the average AEC for each representative unit in a given application by using the following formula:

$$AEC = \left(\sum_{i=1}^{All\_operating\_ponts} (Q_i \times H_i / \eta_{overall})_i \times N_i \right) \times (Sp.Gr) / 5{,}308$$

Where:

AEC = annual energy consumption (kWh),
Q_i = flow rate at the operating point i, gallons per minute (gpm),
H_i = pump head at the operating point i, ft,
N_i = operating hours at the operating point i,
$\eta_{Overall} = \eta_F \times \eta_T \times \eta_M \times \eta_C$ at the operating point i,
η_F = pump efficiency,
η_T = transmission efficiency,
η_M = motor efficiency,
η_C = control system efficiency,
$Sp.Gr$ = specific gravity of the fluid, and
5,308 is a unit conversion constant.

Q_i and H_i are based on the actual operating points of the pump on the pump performance curve for fixed-speed pumps and on the system curve for VSD-driven pumps. For a given application in an equipment class, and for each equipment class overall, DOE requests information and data sources useful for determining each of the factors described above.

***Item** 7-7*	DOE requests comment and recommendation on the range and number of sizes over which the analysis should be carried out for each specific speed in different classes of equipment.

***Item** 7-8*	DOE requests information on current industry practices and recommendations on the selection of representative operating points for a given specific speed. DOE welcomes comment on whether the analysis should be extended to a range of operating points away from BEP.

***Item** 7-9*	DOE requests comment and estimates to establish the mean value and the ranges of likely values for transmission, motor, and motor control efficiencies, as well as the impact of a control on motor performance and efficiency.

8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

The effects of energy conservation standards on customers include a change in operating expense (usually decreased) and a change in purchase price (usually increased). DOE analyzes the net effect on customers by calculating the LCC and PBP using the engineering performance data, the equipment prices, and the energy-use and end-use load characterization data. Inputs to the LCC calculation include the cost to the customer of the installed equipment (purchase price plus installation cost), operating expenses (energy expenses and, if applicable, repair costs and maintenance costs), the lifetime of the equipment, and a discount rate.

8.1 Analytical Approach

DOE plans to conduct an LCC and PBP analysis for each of the representative units for each representative pump equipment class. As illustrated in Figure 8.1, DOE considers the pump selection process in the center of the LCC Analyses flow diagram to reflect product choices by customers. The market size of covered pumps (such as shipments and values) depends on equipment classes and application segments, while energy price varies by end-user sectors. Similarly, a pump's duty profile (including hours of operation and specific duty points) changes in different application segments. In the pump selection process, customers are expected to select pump models (and motors, if applicable) that meet the duty point requirements. Based on pump efficiencies at a specific duty point, annual energy consumption is calculated depending on whether it operates under variable load or constant load. DOE then aggregates the annual energy consumption over a pump's lifetime for the life-cycle cost analysis, taking into account an efficiency degradation factor and a discount rate.

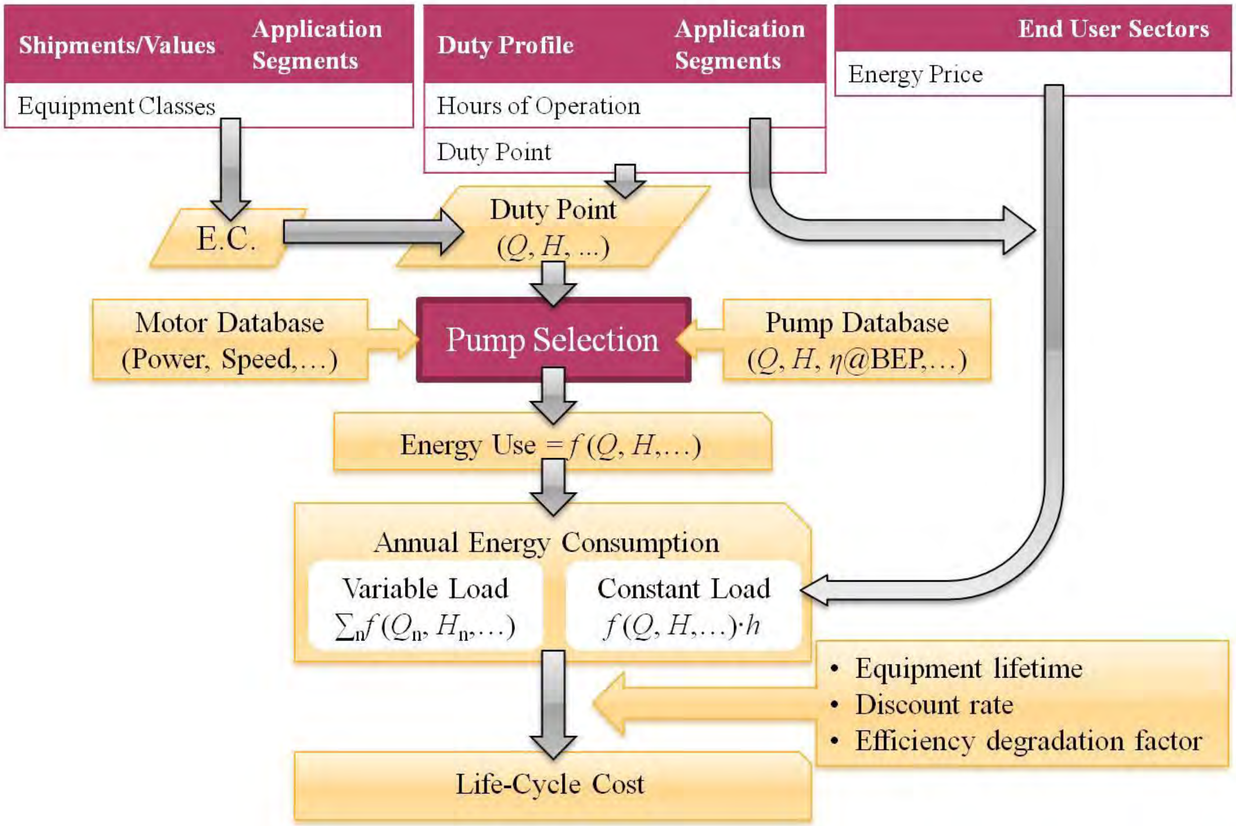

Figure 8.1 Flow Diagram of LCC Analyses for Pumps

DOE conducts the LCC and PBP analysis by modeling both the uncertainty and variability in the inputs using Monte Carlo simulation and probability distributions. The Monte Carlo approach identifies the percentage of consumers benefiting from and being burdened by a prospective standard. The LCC model uses Monte Carlo simulation to sample probability distributions for several of the parameters that affect the LCC. The Monte Carlo simulation is implemented using Microsoft Excel spreadsheets and the Crystal Ball add-in program. Each Monte Carlo simulation would typically consist of 10,000 LCC and PBP calculations. Each calculation uses input values sampled from a probability distribution or defined as single point values. The analysis results are presented as a distribution of LCC values and summary statistics, such as average LCC and standard deviation.

DOE expects to use probability distributions to characterize equipment lifetimes, discount rates, and annual energy use and to represent the degree to which equipment is optimally sized for a given pumping load. DOE may also use probability distributions for distributor markups. DOE expects to use point values to characterize the other LCC inputs, including the manufacturer markup, as these data are available only as single values.

To accurately estimate the percentage of customers that would be affected by a particular standard level, DOE takes into account the distribution of equipment efficiencies expected for the compliance year. In other words, rather than analyzing the impacts of a particular standard level assuming that all consumers are currently purchasing equipment at the baseline level, DOE conducts the analysis by taking into account the full range of equipment efficiencies that customers purchase under the base case (*i.e.*, the case without new energy efficiency standards). By accounting for customers who already purchase more-efficient equipment, DOE avoids overstating the potential benefits from standards. DOE determines the LCC and PBP for a particular standard level relative to the base case distribution of equipment efficiencies. Hence, if the equipment chosen in the base case has an efficiency that meets a given CSL, the LCC and PBP calculations for that customer are not impacted by the standard. For customers not affected by a given CSL, the LCC savings are zero, and the payback period is not defined.

DOE is also required to perform an analysis to determine whether the three-year rebuttable presumption of economic justification applies, that is, whether the additional cost of purchasing a product that meets the standard level would be less than three times the value of the energy savings in the first year. (42 U.S.C. § 6295(o)(2)(B)(iii)) For this analysis, DOE determines the value of the first year's energy savings using the DOE test procedure. The economic justification of CSLs, however, is based on the analysis conducted pursuant to section 325(o)(2)(B)(i) of EPCA. (42 U.S.C. § 6295(o)(2)(B)(i))

The following sections discuss how DOE plans to develop key inputs to the LCC and PBP analysis, including (1) installation costs, (2) energy prices, (3) maintenance and repair costs, (3) equipment lifetime, and (4) discount rates. The other inputs to the LCC and PBP analysis—namely, manufacturer costs, annual energy consumption, and markups for the determination of retail prices—have been discussed previously.

8.2 Installation Costs

The installation cost includes labor, overhead, and any other miscellaneous materials and parts. DOE is aware that there is variability in the costs for commercial and industrial sector pump installations. However, DOE does not have information to suggest that existing installation practices would necessarily change under an energy conservation standard.

Item 8-1 DOE welcomes comment on whether installation costs for pumps increase with higher efficiency equipment.

8.3 Energy Prices

DOE will use tariff-based marginal electricity prices to value electricity savings for commercial and industrial customers. Marginal prices will be developed for the different customer sectors at the census division level. DOE will then use projections of energy prices for commercial and industrial customers by census division from the most recent version of the Energy Information Administration's (EIA's) *Annual Energy Outlook* (*AEO*) to estimate future energy prices. To account for the expenses due to reactive power demand, DOE also intends to survey reactive power prices, principally using data from the EIA.

Item 8-2 DOE welcomes input on the proposed methodology for estimating current and future electricity prices.

8.4 Maintenance and Repair Costs

DOE will take into consideration any expected changes to maintenance and repair costs for the equipment covered in a rulemaking. Small incremental changes in equipment efficiency are expected to incur little or no change in repair and maintenance costs over baseline equipment. For equipment with significant energy efficiency improvements over the baseline, there may be increased repair and maintenance costs, because such equipment may incorporate technologies that are not widely available.

Item 8-3 DOE invites comment on how repair costs may change for more efficient pumps.

8.5 Equipment Lifetime

DOE will use information from catalogs and various literature sources, and input from manufacturers and other stakeholders, to establish pump lifetimes for use in the LCC and subsequent analyses. DOE may consider correlation between pump lifetime, annual operating hours, and loading (*i.e.*, operation away from BEP) if quantitative evidence is found that these factors in the field affect pump lifetimes. DOE believes that the average pump lifetime is 10-15 years, with a maximum of around 25 years.

The service lifetime of centrifugal pumps varies quite widely. The average lifetime of clean water pumps is significantly higher than that of non-clean water pumps, as pumps handling liquids other than clean water are subject to corrosion or abrasion of the wetted parts, or both. Even within the category of clean water pumps, though, the lifetime of centrifugal pumps varies widely based on a variety of application characteristics, such as:

- Whether the pump is immersed in liquid such as in a vertical turbine or submersible style, as immersed or submersible pumps with wetted bearings may be expected to have a shorter mechanical life than pumps such as end suction pumps, which have bearings that are lubricated with clean oil or grease.
- The pump head, horsepower, and speed, as higher values of any of these parameters tend to increase bearing loads and the amount of wear and tear on mechanical seals.
- The temperature of the fluid being pumped, as higher temperature fluids tend to shorten mechanical seal life.

The discussion of service lifetime of pumps is somewhat complicated by the fact that smaller, less expensive pumps are treated as “throwaway” pumps, that is, they are not repaired, but simply run to the point where they no longer deliver the minimum flow desired, or to where they leak excessively and uncontrollably, and then replaced. Typically, this would be the strategy for smaller pumps, 2 or 3 HP and less, and even larger pumps, up to 10 - 25 Hp for some users of pumps. For pumps that are bigger than this threshold of size, the pumps are repaired, with the repair activity including replacing or refurbishing such parts as bearings, mechanical seals, sleeves, wear rings, impellers, etc. This repair cycle is likely to be repeated multiple times throughout the complete life of the pump, which in many cases is as long as the plant or building is in service (30 – 50+ years). In other cases the pump may be prematurely replaced if the system in which the pump operates is being significantly modified, if the conditions of service for the pump dramatically change, or if the major parts of the pump are worn such that a repair is significantly more costly than the purchase of a new pump. Table 8.1 shows DOE's estimates of the lifetime distribution for pump categories that are treated as throwaway pumps. Table 8.2 shows DOE's estimates of the repair cycle distribution for pump categories that are repaired rather than thrown away.

Table 8.1 Lifetime Distribution for Pump Categories

Product Code	**Product Description**	**1st 5th (Yrs.)**	**2nd 5th (Yrs.)**	**3rd 5th (Yrs.)**	**4th 5th (Yrs.)**	**5th 5th (Yrs.)**
3339111448	Centrifugal single and two stage, single and end suction, close coupled with driver	3	7	10	13	17
3339111450	Centrifugal single and two stage, single suction, in-line, close coupled with driver	3	7	10	13	17
3339111496B	Vertical turbine pumps with submersible motors, bowl assemblies	3	6	9	12	15

Table 8.2 Repair Cycle Distribution for Pump Categories

Product Code	**Product Description**	**1st 5th (Yrs.)**	**2nd 5th (Yrs.)**	**3rd 5th (Yrs.)**	**4th 5th (Yrs.)**	**5th 5th (Yrs.)**
3339111452	Centrifugal single stage, single suction, frame or foot mounted, non-ANSI, non-ISO, with or without recessed impeller, all size discharge	2	4	6	8	10
333911144E	Centrifugal single stage, single suction, vertical, in-line frame	1	3	5	7	9
333911144H	Centrifugal single stage, single suction, frame or foot mounted, metallic pumps, built to National or International Standards ANSI B73.1 or ISO2858	1	3	5	7	9
333911145L	Centrifugal single stage, axially spit, double suction, all size discharge	2	4	6	8	10
333911146F	Centrifugal multi-stage, single or double suction, diffuser design, volute or diffuser design, axially split case	2	4	6	8	10
3339111468	Centrifugal multi-stage, single or double suction, diffuser design, radially split case	1	3	5	7	9

Product Code	**Product Description**	**1st 5th (Yrs.)**	**2nd 5th (Yrs.)**	**3rd 5th (Yrs.)**	**4th 5th (Yrs.)**	**5th 5th (Yrs.)**
3339111486	Centrifugal propeller and mixed flow, horizontal and vertical, all sizes.	2	4	6	8	10
3339111496A	Vertical turbine pumps, bowl assemblies, and can and pot type. Excludes those with sub. motor	1	3	5	7	9

Item 8-4 DOE welcomes comment on appropriate pump lifetimes for the equipment classes covered in this rulemaking, as well as data regarding correlation between pump end-use patterns and pump lifetime.

Item 8-5 DOE requests data on the degradation of pump efficiency over a pump's lifetime.

8.6 Discount Rates

The calculation of LCC requires the use of an appropriate discount rate for those commercial or industrial companies that purchase pumps. DOE will derive the discount rates for these commercial and industrial customers by estimating the capital costs for companies that purchase pumps. The cost of capital is commonly used to estimate the present value of cash flows to be derived from a typical company project or investment. Most companies use both debt and equity capital to fund investments, so the cost of capital is the weighted-average cost of equity and debt financing, which is referred to as the weighted-average cost of capital.

Item 8-6 DOE welcomes input on the proposed approaches for estimating discount rates for pump customers.

9. SHIPMENTS ANALYSIS

DOE uses shipment projections by equipment class to calculate the national impacts of standards on energy consumption, NPV, and future manufacturer cash flows. DOE plans to develop shipments projections based on an analysis of key market drivers (*i.e.*, commercial building construction trends, growth in industries that use pumps) for the equipment in this rulemaking.

DOE's approach considers that shipments of pumps are driven by machinery production growth for equipment incorporating pumps and by the economic growth of commercial and industrial sectors that use this equipment. Historical data will be used to establish the relationship between shipments of pumps and the appropriate growth index for sector growth. DOE intends to use private fixed investment data for equipment incorporating pumps from the U.S.

Department of Commerce's Bureau of Economic Analysis to characterize the production of this equipment.

DOE typically projects shipments for a 30-year period beginning with the expected compliance date of any standards.

Item 9-1 DOE welcomes comment on the shipments projection methodology. DOE invites comments regarding the selection of appropriate economic drivers and sources of data for historical shipments and shipment breakdowns by equipment class.

Item 9-2 DOE requests historical shipments or bookings data for each of the considered equipment classes, with further breakdowns where available including, but not limited to, flow, head, specific speed, horsepower, or efficiency.

9.2 Standards Impacts on Shipments

DOE plans to derive standards-case projections using the same data used in the development of the base-case projections. However, because the standards-case forecasts take into account the usual increase in purchase price and the usual decrease in operating costs caused by standards, projected shipments typically deviate from the base case. The magnitude of the difference between the standards-case and base-case shipment projections depends on the estimated purchase price increase, as well as the operating-cost savings from the standard. DOE plans to assess whether the purchase price or the operating cost will have a greater impact on equipment purchase decisions; therefore, standards-case projections may show a change in shipments relative to the base case.

Item 9-3 DOE welcomes comment on how any standard for pumps might impact shipments of the equipment in this rulemaking.

10. NATIONAL IMPACT ANALYSIS

The NIA assesses the aggregate impacts of potential efficiency standards at the national level. Impacts that DOE will report include the NES from potential pump standards (*i.e.*, the cumulative incremental energy savings from pump efficiency standards) and the NPV of the total customer benefits.

A key component of DOE's estimates of NES and NPV are the equipment energy efficiencies projected over time, for the base case (without new standards) and for each of the standards cases. To develop the various standards cases, DOE plans to develop market-share efficiency data (*i.e.*, data on the distribution of equipment shipments by efficiency) for the pump equipment classes DOE is considering.

To estimate the impact that standards may have in the year compliance becomes required, DOE has used "roll-up" and/or "shift" scenarios in its standards rulemakings. Under the "roll-up" scenario, DOE assumes (1) equipment efficiencies in the base case that do not meet the standard level under consideration would "roll up" to meet the new standard level; and (2) equipment shipments at efficiencies above the standard level under consideration would not be affected. Under the "shift" scenario, DOE retains the pattern of the base-case efficiency distribution but re-orients the distribution at and above the new minimum energy conservation standard. For this rulemaking DOE proposes to use their traditional "roll-up" scenario to perform this estimation as it has done in many past standards rulemakings. DOE believes that pump manufacturers are likely to make the minimum investment necessary to roll-up pumps to the standard level and that the efficiency distribution would not be re-oriented at and above the new standard. After DOE establishes the average efficiency for the assumed effective date of a standard, it can estimate future efficiency by using the same rate of projected efficiency growth as for the base-case efficiency trend.

10.1 National Energy Savings

DOE intends to calculate national pump energy consumption for each year beginning with the expected compliance date of any standards. It will calculate national pump energy consumption for the base cases and each standard level analyzed, and the energy savings will be calculated as the difference in energy consumption between the base case and the standards cases. DOE plans to perform this calculation through the use of a spreadsheet model that accounts for the stock of equipment affected by standards.[33] The energy savings are measured over the entire lifetime of products purchased in the 30-year projection period.[34]

DOE has historically presented NES in terms of primary energy savings. On August 18, 2011, DOE announced its intention to use full-fuel-cycle (FFC) measures of energy use and greenhouse gases and other emissions in the national impact analyses and emissions analyses included in future energy conservation standards rulemakings. (76 FR 51282) While DOE stated in that notice that it intended to use the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to conduct the analysis, it also said it would review alternative methods, including the use of the National Energy Modeling System (NEMS). After evaluating both models and the approaches discussed in the August 18, 2011 notice, DOE determined that NEMS is a more appropriate tool for this analysis. 77 FR 49701 (August 17, 2012). Therefore, DOE intends to use NEMS to conduct FFC analyses.

10.2 Net Present Value of User Benefits

To develop the national NPV of user benefits from potential standards, DOE must calculate annual energy expenditures and annual equipment expenditures for the base case and the standards cases. DOE calculates annual energy expenditures from annual energy consumption by incorporating forecasted energy prices, using the shipment and average energy efficiency projections described in section 9. DOE calculates annual equipment expenditures by multiplying the price per unit times the projected shipments. The difference each year between

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[33] Several examples of NES spreadsheet models from previous rulemakings can be found on DOE's website at: http://www.eere.energy.gov/buildings/appliance_standards/.

[34] In the past DOE presented energy savings results for only the 30-year period that begins in the year of compliance. In the calculation of economic impacts, however, DOE considered operating cost savings measured over the entire lifetime of products purchased in the 30-year period. DOE has chosen to modify its presentation of national energy savings to be consistent with the approach used for its national economic analysis.

energy bill savings and increased equipment expenditures is the net savings (if positive) or net costs (if negative). DOE discounts these annual values to the present time and sums them to provide a NPV. According to U.S. Office of Management and Budget (OMB) guidelines, DOE will calculate NPV using real discount rates of three percent and seven percent (OMB, *Circular A-4: Regulatory Analysis* (2003).

11. CUSTOMER SUBGROUP ANALYSIS

The LCC analysis described in section 8 analyzes the impacts of energy conservation standards on all users of commercial and industrial pumps. For the subgroup analysis, DOE divides users into subgroups, which comprise a subset of the population that is likely, for one reason or another, to be affected disproportionately by new or revised energy conservation standards (*e.g.*, small businesses or firms that use pumps in particular applications where energy savings are likely to be small[35]). The purpose of a subgroup analysis is to determine the extent of this disproportional impact. DOE will work with stakeholders to identify any subgroups for this consideration and will conduct a subgroup analysis during the NOPR stage of this rulemaking.

Item 11-1 DOE welcomes comment on what, if any, user subgroups are appropriate in considering standards for pumps.

12. MANUFACTURER IMPACT ANALYSIS

DOE intends the MIA to provide an assessment of the potential impacts of energy conservation standards on manufacturers of commercial and industrial pumps. A wide range of quantitative and qualitative effects may occur following the adoption of a standard that may require changes to manufacturing practices. DOE will identify these potential effects through interviews with manufacturers and other interested parties.

For the NOPR, DOE will conduct an industry-wide cash-flow analysis using the Government Regulatory Impact Model (GRIM), identify and analyze subgroups of manufacturers whose businesses vary significantly from the industry as a whole, perform a competitive impacts assessment, and review the cumulative regulatory burden for the industry.

12.1 Sources of Information for the Analysis

Many of the analyses described earlier provide information that DOE will use as inputs for the MIA. Such information includes financial parameters developed in the market assessment (section 3.1), cost data developed in the engineering analysis (section 5), and shipments projections (section 9). DOE will supplement this information with information gathered during manufacturer interviews.

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[35] These firms differ from any pump manufacturers who may qualify as a small business under the size standards established by the Small Business Administration. DOE analyzes impacts to these small businesses, which would be directly impacted by any final standards DOE might establish, as required by the Regulatory Flexibility Act (see section 12.3).

During the preliminary analysis phase, DOE will conduct interviews with manufacturers to gain insight into the range of possible impacts from potential energy conservation standards. These interviews will coincide with preliminary technical interviews for the engineering analysis.

During the NOPR phase, DOE will conduct more detailed MIA interviews with manufacturers. The interview process plays a key role in the MIA, because it provides an opportunity for directly affected parties to express their views on important issues. During the interviews, DOE will solicit information on the possible impacts of potential standards on manufacturing costs, product prices, sales, direct employment (*i.e.,* employment for the manufacturer only), capital assets, and industry competitiveness. Both qualitative and quantitative information are valuable in this analysis. DOE prefers an interactive interview process because it helps to clarify manufacturer input and provides the opportunity to identify additional issues.

DOE will ask interview participants to identify confidential information, and will protect the confidentiality of the information provided as explained in section 5. DOE will also ask participants to identify any information they wish to have included in the public record, but do not want to have associated with their interviews (thereby identifying that particular manufacturer). DOE will incorporate this information into the public record without attribution.

DOE will collate the interview results and prepare a summary of the major issues and outcomes. This summary will become part of the TSD for this rulemaking.

12.2 Industry Cash Flow Analysis

The industry cash flow analysis will rely primarily on the GRIM. DOE uses the GRIM to analyze the financial impacts of new or amended energy conservation standards on the industry that produces the products covered by the standard.

The GRIM uses a number of factors—annual expected revenues; manufacturer costs such as costs of goods sold; selling, general, and administrative (SG&A) costs; research and development costs; product conversion costs; taxes; capital expenditures (both ordinary capital expenditures and those related to standards); and working capital requirements—to determine annual cash flows associated with a new standard, beginning from the announcement of the standard and continuing through the analysis period. DOE compares the results against base-case projections that involve no new standards. The financial impact of new standards is the difference between the two sets of discounted annual cash flows, or the differences between the base-case and standards-case industry net present values (INPV). Other performance metrics, such as return on invested capital, are also available from the GRIM.

DOE will gather the inputs needed for the GRIM from two primary sources: (1) the analyses conducted to this point; and (2) interviews with manufacturers and other interested parties. As discussed, information gathered from previous analyses will include financial parameters, manufacturing costs, price forecasts, and shipment projections. Interviews with manufacturers and other interested parties will supplement this information.

12.3 Manufacturer Subgroup Analysis

Average industry cost values may not reveal differential impacts among pump manufacturer subgroups. Smaller manufacturers, niche players, and manufacturers exhibiting a cost structure that differs significantly from the industry average may be affected differently by standards. Ideally, DOE would consider the impact on every firm individually. In highly-concentrated industries, this may be possible. In industries having numerous participants, however, DOE uses the results of the market and technology assessment to group manufacturers into subgroups, as appropriate. For commercial and industrial pumps, DOE is interested in feedback about potential subgroups, including small businesses. DOE will conduct a Regulatory Flexibility Act analysis to determine the impacts of any standards on small businesses consistent with the Regulatory Flexibility Act. The manufacturer subgroup impact analysis will calculate cash flows separately for each class of manufacturer.

Item 12-1 DOE seeks comments on the subgroups of the pumps equipment manufacturers that it should consider in a manufacturer subgroup analysis.

12.4 Competitive Impacts Assessment

EPCA directs DOE to consider any lessening of competition likely to result from the imposition of standards. (42 U.S.C. 6295(o)(2)(B)(i)(V)) It further directs the Attorney General to determine in writing the impacts, if any, of any lessening of competition likely to result from standards. (42 U.S.C. 6295(o)(2)(B)(ii))

DOE will make a determined effort to gather firm-specific financial information and impacts and report the aggregated impact of the amended standard on manufacturers. The competitive impacts analysis will focus on assessing the impacts on smaller manufacturers. DOE will base the assessment on manufacturing cost data and information collected from interviews with manufacturers. The manufacturer interviews will focus on gathering information that would help in assessing asymmetrical cost increases to some manufacturers, increased proportion of fixed costs potentially increasing business risks, and potential barriers to market entry (*e.g.*, proprietary technologies). DOE will provide the Attorney General with a copy of the NOPR for consideration in his evaluation of the impact of standards on the lessening of competition. DOE will publish the Attorney General's letter and address any related comments in the final rule.

12.5 Cumulative Regulatory Burden

Other regulations (Federal, State, local, or international) may apply to manufacturers of pumps covered under this rulemaking and to other equipment made by these manufacturers. Multiple regulations may result in a significant, cumulative regulatory burden on these manufacturers. DOE will consider the impact on these manufacturers of multiple, product-specific regulatory actions.

Item 12-2 DOE welcomes comments on what other existing regulations or pending regulations it should consider in its examination of cumulative regulatory burden.

13. EMISSIONS ANALYSIS

In the emissions analysis, conducted in the NOPR phase, DOE will estimate the reduction in power sector emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), and mercury (Hg) from potential energy conservation standards for pumps. In addition, DOE will estimate emissions impacts in production activities (extracting, processing, and transporting fuels) that provide the energy inputs to power plants. These are referred to as "upstream" emissions. Together, these emissions account for the FFC. In accordance with DOE's FFC Statement of Policy (76 FR 51281 (Aug. 18, 2011)), the FFC analysis includes impacts on emissions of methane (CH_4) and nitrous oxide (N_2O), both of which are recognized as greenhouse gases.

DOE will conduct the emissions analysis using emissions factors derived from data in EIA's most recent *Annual Energy Outlook* (*AEO*), supplemented by data from other sources. EIA prepares the *AEO* using NEMS. Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions. The text below refers to *AEO 2012*.

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap-and-trade programs. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous States and the District of Columbia (D.C.). SO_2 emissions from 28 eastern States and D.C. were also limited under the Clean Air Interstate Rule (CAIR, 70 FR 25162 (May 12, 2005)), which created an allowance-based trading program that operates along with the Title IV program. CAIR was remanded to the U.S. Environmental Protection Agency (EPA) by the U.S. Court of Appeals for the District of Columbia Circuit, but it remained in effect. See *North Carolina v. EPA*, 550 F.3d 1176 (D.C. Cir. 2008); *North Carolina v. EPA*, 531 F.3d 896 (D.C. Cir. 2008). On July 6, 2011, EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). The *AEO 2012* emissions factors assume the implementation of the CSAPR.[36]

The attainment of emissions caps is typically flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the adoption of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO_2 emissions covered by the existing cap-and-trade system, but it concluded that negligible reductions in power sector SO_2 emissions would occur as a result of standards.

Beginning in 2015, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants, which were announced by EPA on December 21,

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[36] On December 30, 2011, the D.C. Circuit stayed the new rules while a panel of judges reviews them, and told EPA to continue administering CAIR. See *EME Homer City Generation, LP v. EPA*, Order, No. 11-1302, Slip Op. at *2 (D.C. Cir. Dec. 30, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR. See *EME Homer City Generation, LP v. EPA*, No. 11-1302, 2012 WL 3570721 at *24 (D.C. Cir. Aug. 21, 2012). The court again ordered EPA to continue administering CAIR. *AEO 2012* had been finalized prior to both these decisions, however. DOE understands that CAIR and CSAPR are similar with respect to their effect on emissions impacts of energy efficiency standards.

2011. 77 FR 9304 (Feb. 16, 2012). In the final MATS rule, EPA established a standard for hydrochloric acid (HCl) as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2012* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2015. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, NEMS shows a reduction in SO_2 emissions when electricity demand decreases (*e.g.,* as a result of energy efficiency standards). Emissions will be far below the cap that would be established by CSAPR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO_2 emissions in 2015 and beyond.

CSAPR established a cap on NO_X emissions in the 28 eastern States and the District of Columbia. Energy conservation standards are expected to have little or no effect on NO_X emissions in those States covered by CSAPR because excess NO_x emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_x emissions. However, standards would be expected to reduce NO_x emissions in the States not affected by CSAPR, so DOE estimates NO_X emissions reductions from potential standards for these States.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce Hg emissions.

Power plants may emit particulates from the smoke stack, which are known as direct particulate matter (PM) emissions. NEMS does not account for direct PM emissions from power plants. DOE is investigating the possibility of using other methods to estimate reduction in PM emissions due to standards. The great majority of ambient PM associated with power plants is in the form of secondary sulfates and nitrates, which are produced at a significant distance from power plants by complex atmospheric chemical reactions that often involve the gaseous emissions of power plants, mainly SO_2 and NO_x. The monetary benefits that DOE estimates for reductions in SO_2 and NO_x emissions resulting from standards are in fact primarily related to the health benefits of reduced ambient PM.

Item 13-1 DOE seeks input on its approach to conducting the emissions analysis for commercial and industrial pumps.

14. MONETIZING CARBON DIOXIDE AND OTHER EMISSIONS REDUCTIONS

DOE plans to consider the estimated monetary benefits likely to result from the reduced emissions of CO_2 and NO_X that are expected to result from each of the standard levels considered.

In order to estimate the monetary value of benefits resulting from reduced emissions of CO_2, DOE plans to use the most current social cost of carbon (SCC) values developed or agreed to by an interagency process. The SCC is intended to be a monetary measure of the incremental damage resulting from greenhouse gas (GHG) emissions, including, but not limited to, net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the harms associated with climate change will raise serious questions of science, economics, and ethics. But with full regard for the limits of both quantification and monetization, the SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

At the time of this notice, the most recent interagency estimates of the potential global benefits resulting from reduced CO_2 emissions in 2015, expressed in 2011\$, were \$6.1, \$25.4, \$41.0, and \$77.7 per metric ton avoided. For emissions reductions that occur in later years, these values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although DOE will give preference to consideration of the global benefits of reducing CO_2 emissions. To calculate a present value of the stream of monetary values, DOE will discount the values in each of the four cases using the discount rates used to obtain the SCC values in each case.

DOE recognizes that scientific and economic knowledge continues to evolve rapidly as to the contribution of CO_2 and other GHG to changes in the future global climate and the potential resulting damages to the world economy. Thus, these values are subject to change.

DOE also intends to estimate the potential monetary benefit of reduced NO_X emissions resulting from the standard levels it considers. For NO_X emissions, available estimates suggest a very wide range of monetary values for NO_X emissions, ranging from \$460 to \$4,722 per ton in 2011\$.[37] In accordance with OMB guidance, DOE will conduct two calculations of the monetary benefits derived using each of the economic values used for NO_X, using real discount rates of 3 percent and 7 percent.[38]

DOE is investigating appropriate valuation of Hg emissions. Whether monetization of reduced Hg emissions will occur in this rulemaking is not yet certain.

Item 14-1 DOE requests comments on the approach it plans to use for estimating monetary values associated with emissions reductions.

15. UTILITY IMPACT ANALYSIS

In the utility impact analysis, DOE analyzes the changes in electric installed capacity and generation that result for each trial standard level. The utility impact analysis uses a variant of

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[37] For additional information, refer to the U.S. Office of Management and Budget, Office of Information and Regulatory Affairs, 2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities, Washington, DC.

[38] OMB, Circular A-4: Regulatory Analysis (Sept. 17, 2003).

EIA's NEMS[39], which 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.* DOE uses a variant of this model, referred to as NEMS-BT[40], to account for selected utility impacts of new or amended energy conservation standards. DOE's analysis consists of a comparison between model results for the most recent *AEO* Reference Case and for cases in which energy use is decremented to reflect the impact of potential standards. For the analysis of standards on commercial and industrial pumps, DOE will use the version of NEMS used for the most recent *AEO.*

Item 15-1 *DOE welcomes input from interested parties on its proposed approach to conduct the utility impact analysis.*

16. EMPLOYMENT IMPACT ANALYSIS

The employment impact analysis examines indirect employment impacts from standards, which consist of the net jobs created or eliminated in the national economy, other than in the manufacturing sector being regulated, caused by: (1) reduced spending by end users on energy; (2) reduced spending on new energy supply by the utility industry; (3) increased spending on new equipment to which the new standards apply; and (4) the effects of those three factors throughout the economy. (Direct employment impacts are any changes in the number of employees of manufacturers of the equipment subject to standards; the MIA will address these impacts.)

One method for assessing the possible effects on the demand for labor of such shifts in economic activity is to compare sector employment statistics developed by the Labor Department's Bureau of Labor Statistics (BLS). The BLS regularly publishes its estimates of the number of jobs per million dollars of economic activity in different sectors of the economy, as well as the jobs created elsewhere in the economy by this same economic activity. Data from BLS indicate that expenditures in the utility sector generally create fewer jobs (both directly and indirectly) than expenditures in other sectors of the economy.[41] There are many reasons for these differences, including wage differences and the fact that the utility sector is more capital-intensive and less labor-intensive than other sectors. Energy conservation standards have the effect of reducing consumer utility bills. Because reduced consumer expenditures for energy likely lead to increased expenditures in other sectors of the economy, the general effect of efficiency standards is to shift economic activity from a less labor-intensive sector (*i.e.*, the utility sector) to more labor-intensive sectors (*e.g.*, the retail and service sectors).

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[39] 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 2003*, DOE/EIA-0581(2003), (March 2003).

[40] DOE/EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on DOE/EIA assumptions, DOE refers to it by the name NEMS-BT. (BT is DOE's Building Technologies Program, under whose aegis this work has been performed)

[41] See Bureau of Economic Analysis, Regional Multipliers: A User Handbook for the Regional Input-Output Modeling System (RIMS II). Washington, DC. U.S. Department of Commerce, 1992.

In the NOPR stage of this rulemaking, DOE plans to estimate indirect national employment impacts using an input/output model of the U.S. economy called Impact of Sector Energy Technologies version 3.1.1 (ImSET).[42] ImSET is a special-purpose version of the "U.S. Benchmark National Input-Output" (I–O) model, which was designed to estimate the national employment and income effects of energy-saving technologies. The ImSET software includes a computer-based I–O model having structural coefficients that characterize economic flows among 187 sectors most relevant to industrial, commercial, and residential building energy use.

DOE notes that ImSET is not a general equilibrium forecasting model and understands the uncertainties involved in projecting employment impacts, especially changes in the later years of the analysis. Because ImSET does not incorporate price changes, the employment effects predicted by ImSET may over-estimate actual job impacts over the long run. DOE may consider the use of other modeling approaches for examining long-run employment impacts.

Item 16-1 DOE welcomes feedback on its proposed approach to assessing national employment impacts.

17. REGULATORY IMPACT ANALYSIS

In the NOPR stage of this rulemaking, DOE will prepare a regulatory impact analysis that will address the potential for non-regulatory approaches to supplant or augment energy conservation standards to improve the efficiency of pumps on the market. DOE recognizes that voluntary or other non-regulatory efforts by manufacturers, utilities, and other interested parties can result in substantial efficiency improvements. DOE intends to analyze the likely effects of non-regulatory initiatives and compare those effects with those projected to result from standards. DOE will attempt to base its assessment on the actual impacts of any such initiatives to date, but will also consider information presented regarding the impacts that any existing initiative might have in the future.

If DOE proposes energy conservation standards for pumps and the NOPR constitutes a significant regulatory action, DOE would prepare and submit to OMB for review the assessment of costs and benefits required under section 6(a)(3) of Executive Order 12866, "Regulatory Planning and Review," 58 FR 51735 (October 4, 1993).

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[42] J. M. Roop, M. J. Scott, and R. W. Schultz, ImSET 3.1: Impact of Sector Energy Technologies, PNNL-18412, Pacific Northwest National Laboratory, 2009. Available at: www.pnl.gov/main/publications/external/technical_reports/PNNL-18412.pdf

APPENDIX A - LIST OF ITEMS FOR COMMENT

Item 1-1 DOE seeks comment on its proposal to cover only clean water pumps in this rulemaking. 3

Item 1-2 DOE requests comment on whether it should rely on a definition of 'clean water' to determine coverage of pumps, as in the EU, or if, instead, the definition of 'clean water pumps' should include physical characteristics that distinguish pumps designed for clean water or exclude pumps designed for other purposes. 4

Item 1-3 DOE seeks comment on the list of physical differences that may exist between pumps designed for clean water and pumps designed for other substances. Specifically, (1) is the list accurate and exhaustive, (2) do the differences impact efficiency, and (3) do the differences have increased cost? 4

Item 1-4 DOE seeks comment on whether it should consider standards for pumps designed for non-water liquids that contain limited solids in this rulemaking. DOE is specifically interested in ANSI chemical process pumps, API 610 pumps, sealless (magnetic drive, canned, or cantilever) pumps, sanitary pumps, refrigerant pumps, and general industrial pumps. When suggesting pump types for which standards should not be considered, please be specific as to the reason why. 4

Item 1-5 DOE requests comment on whether any design changes made to standard clean water pumps would carry through to pumps designed for other applications. 4

Item 1-6 DOE seeks comment on its proposal to consider standards for rotodynamic pumps and not positive displacement pumps. In particular, DOE requests comment on the extent of the overlap between rotodynamic and positive displacement pumps and whether there are certain categories of rotodynamic pumps (pump types and ranges of flow and specific speed) for which positive displacement pumps could be a direct replacement. 4

Item 1-7 DOE seeks comment on its proposal to consider standards for pumps not covered in the EU. 5

Item 1-8 DOE seeks comment on its development of pump equipment categories and whether these categories provide an appropriate basis for developing equipment classes. (See section 3.2.) 6

Item 1-9 DOE seeks comment on whether standards for any additional pump categories should be considered. In particular, DOE is interested in pump categories that may have significant potential for energy savings. 6

Item 1-10 DOE seeks comment on the pump types as described by ANSI/HI nomenclature that fall into the equipment categories set forth in Table 1.1. For example, pump type OH1 would be classified as an end suction frame mounted pump. For ANSI/HI pump types that would not fall into the categories in Table 1.1, please provide a specific reason, such as "solids-handling only." 6

Item 1-11 DOE seeks comment on whether wet-running circulator-type pumps should be covered in this rulemaking. 6

Item 1-12 DOE seeks comment on the market size for wet-running circulators in the United States, including the split between commercial and residential applications in terms of physical size or other features, as well as the potential for growth of the market for circulators in commercial applications. 6

Item 1-13 DOE requests comment on which parameters, if any, should be added to this rulemaking. For each parameter proposed, please include the rationale and the type of

Item 1-27 DOE requests comment on whether maximum solids diameter, which is a parameter provided with many pump curves, could be used in the definition of 'clean water'. 14

Item 1-28 DOE requests comment on its proposal to follow the EU approach using pump efficiency if pumps are defined without the motor or controls. DOE is especially interested in whether a pump should have to meet a standard at multiple load points, or if a weighted average metric should be developed. 18

Item 1-29 DOE requests comment on the selection of 75% BEP flow as the part-load point and 110% as the overload point and whether these are the most appropriate points to encourage broad pump efficiency curves. 18

Item 1-30 DOE requests comment on whether the use of an overall efficiency metric for submersible pumps would cause problems for manufacturers, as the EU metric is pump efficiency 18

Item 1-31 DOE requests comment on whether the metric for vertically suspended pumps should be bowl efficiency rather than pump efficiency. 19

Item 1-32 DOE requests comment on its proposal to adapt the EU standard metric to overall efficiency for pumps sold with both motors and VSDs. DOE is also interested in whether additional test points should be added below 75% of BEP flow to address more of the operating range of pumps with VSDs. 19

Item 1-33 DOE requests comment on the appropriate metric to capture the energy efficiency impacts of VSDs. DOE is interested in whether test points at BEP, 75% BEP flow, and 110% BEP flow are appropriate for this metric and whether additional test points should be added below 75% BEP flow to address more of the operating range of pumps with VSDs. DOE is also interested in whether pumps should be required to meet minimum levels at multiple points or if a weighted average metric should be developed. 22

Item 1-34 DOE requests comment on whether the metric for regulatory option 2 and 3 should include an overload test point based on overspeeding. 23

Item 1-35 DOE recognizes that the same pump may in some cases be sold alone or may be sold in conjunction with a motor or motor/control package. DOE seeks comment on any issues that may result from having different metrics for pumps sold alone and pumps sold with motors or VSDs. 24

Item 1-36 DOE seeks comment regarding the implementation methodology described in this section, including whether basing efficiency on flow and specific speed is appropriate and, if so, whether the EU surface should be used as is, with adjusted Cs, or with modified shapes (adjustment of all coefficients). The last option would allow type- and efficiency level-specific surfaces. DOE also seeks comment on whether other parameters or combinations of parameters would be more appropriate or easier to implement, such as flow and head (instead of specific speed). 29

Item 1-37 DOE requests data that would help it improve its database, specifically performance data (i.e., head, flow, power, and efficiency at BEP and multiple additional points) for clean water pumps from catalogs not available on PUMP-FLO 29

Item 1-38 DOE seeks comment on how to calculate specific speed (with regard to flow) for double suction axial split pumps and axially split multi-stage pumps with a double-suction first stage (i.e., whether to use total flow ore one-half the flow). 29

Item 1-39 DOE seeks test data for pumps at 75% and 110% BEP flow points that would allow it to better analyze potential efficiency levels for these points. 30

Item 1-40 DOE requests comment on the appropriateness of setting a standard based on a full impeller. 31

Item 1-41 DOE requests comment on standards based on certain numbers of stages for radially split multi-stage and submersible pumps. DOE also seeks comment on whether the same approach could be taken for axially split multi-stage pumps. 31

Item 1-42 DOE requests data on the percent of pumps sold with a full impeller, as well as the distribution of pump sales with reduced impellers (as a percentage of full impeller). 31

Item 1-43 DOE requests comment on the use of the ANSI/HI 14.6-2011, ANSI/HI 11.6-2012, , ISO 9906-2012, and ISO 5198-1999 test procedures, as well as any other test procedures, as a basis for the development of a DOE test procedure, including any modifications or additions that may be necessary. 34

Item 1-44 DOE requests comment on the scope of each test procedure with respect to the equipment for which DOE is considering standards, as well as any limitations of these test procedures. 34

Item 1-45 DOE is also interested in the pros and cons of using a thermodynamic approach to determining pump or pumping system efficiency, as in ISO 5198-1999. 34

Item 1-46 DOE requests comment on use of "Grade 1" from ANSI/HI 14.6-2011 tolerances for all pump categories and whether it places any additional burden associated with performing testing requirements for all covered equipment classes. 35

Item 1-47 DOE requests comment on the applicable test procedures for complete pump, motor, and VSD system packages. 35

Item 1-48 DOE requests comment on the accuracy of different measurement equipment used to measure pump power, input power to a motor or VSD, pump flow, head, or other parameters and their impact on the accuracy of the measured pump efficiency. DOE also requests comment on the calibration frequency required to maintain sufficient equipment accuracy. 35

Item 1-49 DOE requests comment on the applicability of calculation methods to determine rated pump efficiencies from similar, tested pump efficiencies. 35

DOE requests comment on the number of unique pump models manufacturers would have to test, as well as the ability for a calculation method to reduce testing burden. DOE also requests comment on the reduction in test accuracy when using a calculation method to determine rated efficiency of a unit. 35

Item 1-50 .... **Error! Bookmark not defined.**

Item 1-51 DOE seeks comment on whether a labeling rule would be technologically or economically feasible, result in a significant conservation of energy, or assist customers in making purchasing decisions. 39

Item 1-52 DOE seeks comment on information that it should consider requiring for display on any prospective label, as well as factors DOE should consider regarding the size, format, and placement of any such label. 39

Item 3-1 DOE requests information that would contribute to the market assessment for the pumps that would be covered in this rulemaking, especially for those equipment classes designated in section 3.2. Examples of information sought include current equipment features and efficiencies, equipment feature and efficiency trends, and historical equipment shipments and prices. 42

Item 3-2 DOE requests input on its identification of product codes in the U.S. Census data that match the equipment classes proposed for coverage in this rulemaking. 45

Item 3-3 DOE requests feedback on its estimates of the disaggregation of pump exports and imports to product codes, its estimates of the percentage of shipments of clean water pumps, and its estimates of the percent of shipments sold with motors by the pump manufacturer. 45

Item 3-4 DOE welcomes comments on which performance-related features or design characteristics DOE should consider to define pump equipment classes. 52

Item 3-5 DOE requests information regarding the utility of different pump categories proposed for coverage that would warrant separate equipment classes. For example, could end suction pumps be a single equipment class, or are the breakdowns shown necessary to preserve equipment utility that would affect performance? Could axially and radially split multi-stage pumps be a single equipment class? Could all vertical turbine pumps (both submersible and non-submersible) be a single equipment class? 53

Item 3-6 DOE requests information on whether any of the equipment proposed for coverage provides utility that requires further breakdown from the categories shown in Table 3.8. For example, do multi-stage pumps with a double suction first stage require a separate equipment class? Do vertical turbine can pumps require a separate equipment class from vertical turbine lineshaft pumps? 53

Item 3-7 DOE requests comment on whether equipment classes can be developed for pump categories that would always be used in variable load applications. 53

Item 3-8 DOE requests comment on whether it should consider using Reynolds number instead of flow in setting minimum efficiency standards for pumps and whether this choice would prevent adding design speed as an additional parameter. DOE notes that there are multiple methods of calculating Reynolds number for pumps and that all calculations do not produce the same relative results. As a result, DOE seeks comment on the most appropriate form of Reynolds number for pumps. 56

Item 3-9 DOE requests comment on which method of surface fitting produces the most appropriate results for both cases: (1) a smaller pump at higher speed compared to a larger pump at lower speed; and (2) identical pumps running at two different speeds. DOE requests comment on whether these relationships are expected to differ by equipment class. 60

Item 3-10 DOE requests comment on the use of pump design speed as a feature that distinguishes equipment classes. In particular, DOE seeks comment on whether pumps designed for different rotating speeds perform differently enough to warrant separate equipment classes. DOE also requests comment on any physical differences between pump models offered at different speeds and the nature of those differences, including whether DOE could determine by physical inspection at what speeds a pump can safely operate... 61

Item 3-11 DOE requests comment on the testing and compliance burden on manufacturers under the approaches set forth above. 61

Item 3-12 DOE requests comment on whether it could require all pumps in a given equipment class to be tested at (a) certain speed(s) and, if so, which speed(s) is (are) most appropriate. 61

Item 3-13 DOE requests comment on how manufacturers in the EU are determining the minimum efficiency required for a pump offered at multiple speeds. 61

Item 3-14 DOE welcomes comment on the technology options identified in this section, including further details on methods (such as lists of specific methods for each listed broad option) and potential efficiency gains, as well as information on whether the method in

Item 6-2 DOE requests comments and additional information on the appropriate way to establish distribution channel percentages across equipment classes and application (market) segments for the current rulemaking. In particular, DOE seeks information on the percentage by market segment (i.e., agriculture, municipal, commercial, industrial, and other markets) of direct sales, OEM sales, wholesaler to customer sales, wholesaler to contractor sales, and other sales. DOE seeks this information over the total market. 75

Item 6-3 DOE seeks comment on other sources of relevant data that could be used to characterize markups for commercial and industrial pumps. 76

Item 6-4 DOE requests feedback on its proposal to use incremental distribution channel markups. 76

Item 6-5 DOE seeks comment on appropriate transportation and shipping costs to include in the analysis and whether those costs are likely to vary for higher efficiency commercial and industrial pumps. 76

Item 7-1 DOE requests input and recommendations for identifying high sales volume and large installed base application segments corresponding to specific applications for which the pumps used may have similar duty profiles. 77

Item 7-2 DOE welcomes recommendations on sources of data or analysis methods that would provide end-use duty profiles for each of the equipment classes of pumps covered under this rulemaking in the major application segments. 77

Item 7-3 DOE requests input on ways to characterize pump sizing and selection practices for different equipment classes and applications. 77

Item 7-4 DOE requests comment on the degree of oversizing prevalent in different application segments. 78

Item 7-5 DOE welcomes comment on methods for determining nominal (non-market segment specific) duty profiles for pump equipment classes considered in this rulemaking. 78

Item 7-6 DOE welcomes comment on the current penetration level of VSDs in the installed base of equipment in each application segment for each of the equipment classes considered in this rulemaking. DOE also welcomes comment on the baseline condition for applications without VSDs, such as running at full load, use of a throttling valve, etc. 78

Item 7-7 DOE requests comment and recommendation on the range and number of sizes over which the analysis should be carried out for each specific speed in different classes of equipment. 79

Item 7-8 DOE requests information on current industry practices and recommendations on the selection of representative operating points for a given specific speed. DOE welcomes comment on whether the analysis should be extended to a range of operating points away from BEP. 79

Item 7-9 DOE requests comment and estimates to establish the mean value and the ranges of likely values for transmission, motor, and motor control efficiencies, as well as the impact of a control on motor performance and efficiency. 79

Item 8-1 DOE welcomes comment on whether installation costs for pumps increase with higher efficiency equipment. 81

Item 8-2 DOE welcomes input on the proposed methodology for estimating current and future electricity prices. 81

Item 8-3 DOE invites comment on how repair costs may change for more efficient pumps. .. 82

APPENDIX B - COMPARISON OF THE U.S. PUMP MARKET TO THE EU PUMP MARKET

In an effort to determine whether the specifics of the European Union (EU) water pumps regulation have a bearing on the U.S. market, DOE looked at the EU minimum efficiency indexes (MEIs) for End-Suction Closed Coupled (ESCC), End-Suction Frame Mounted (ESFM), and Vertical Inline (IL) pumps and determined what percent of pumps in its database would be cut off by those MEIs.

The EU MEI is related to the C value in the following efficiency formula:

$$\eta_{\mathrm{BEP}} = -0.85\,(\ln Q)^2 - 0.38\,(\ln Q \cdot \ln Ns) - 11.48\,(\ln Ns)^2 + 13.46 \ln Q + 88.59 \ln Ns - C$$

Where:

Q is flow ($m^3\ h^{-1}$), and
Ns is specific speed (min^{-1}).

The *C* values vary for every equipment class and MEI (ranging from 5% to 80%).

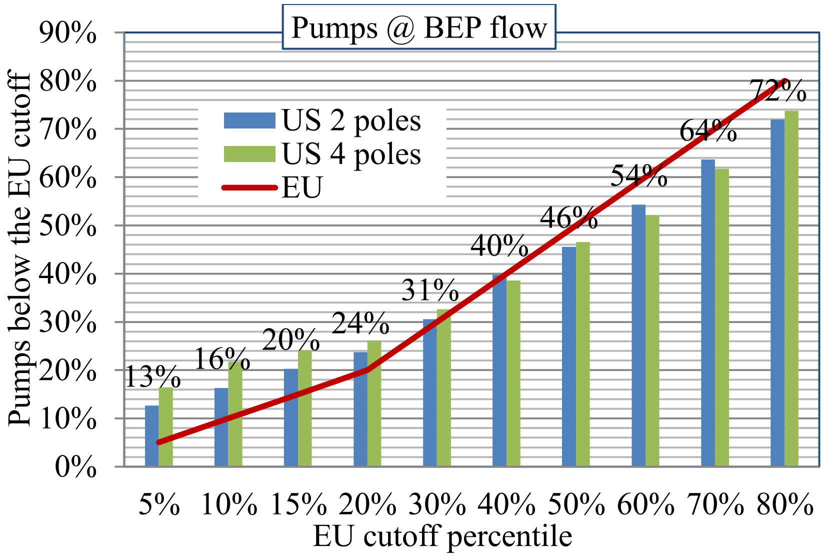
DOE used the five to six points of pump efficiency data provided by PUMP-FLO to interpolate efficiency at 75% of BEP (Best Efficiency Point) flow and 110% of BEP flow. Efficiency at BEP was provided for all pumps. DOE then compared these efficiency values to those calculated using the EU equation (accounting for different units) for all MEIs to determine whether a given pump would pass or fail each MEI. DOE then calculated the percent of all pumps for a given pump type that would be cut-off for each MEI. DOE performed these calculations for BEP only, 75% of BEP flow only, 110% of BEP flow only, and the combination of all three points (where a failure at any one point meant that pump would be cut-off by that MEI). These results are summarized in the sections B1 through B3 for three pump types.

B1. End-Suction Closed Coupled (ESCC) pumps

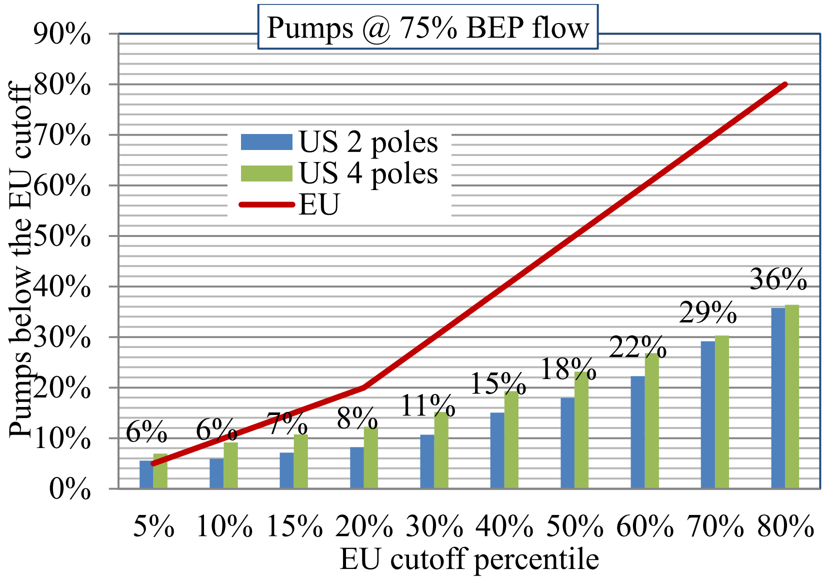
The *C* values for 2-pole and 4-pole ESCC pumps are listed in Table B.1. Figure B.1 compares the ESCC pumps in the U.S. market to various EU MEI standards.

Table B.1 EU Values of *C* for ESCC Pumps

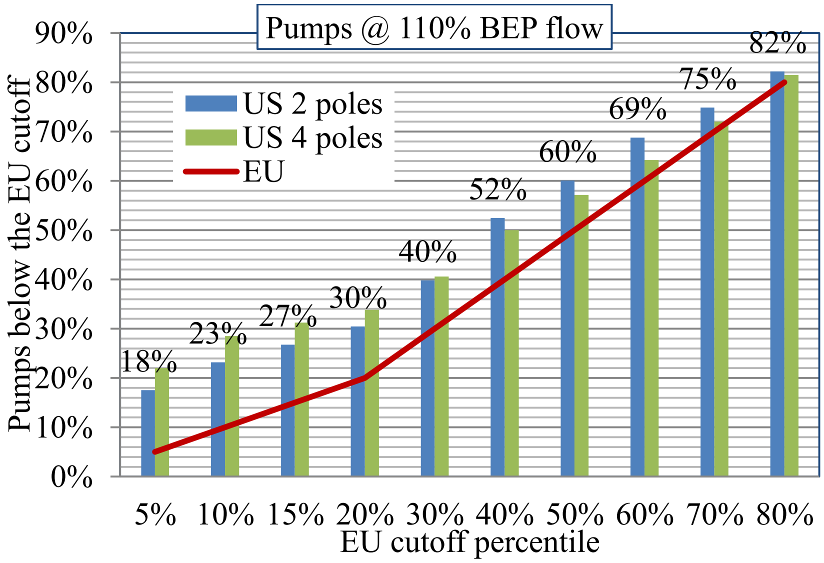
	Quantity cut-off									
C	**5%**	**10%**	**15%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**
ESCC 4 poles	134.39	132.74	132.07	131.2	129.77	128.46	127.38	126.57	125.46	124.07
ESCC 2 poles	137.32	135.93	134.86	133.82	132.23	130.77	129.86	128.8	127.75	126.54


Pumps @ BEP flow
Pumps below the EU cutoff
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
US 2 poles
US 4 poles
EU
13%
16%
20%
24%
31%
40%
46%
54%
64%
72%
5%
10%
15%
20%
30%
40%
50%
60%
70%
80%
EU cutoff percentile

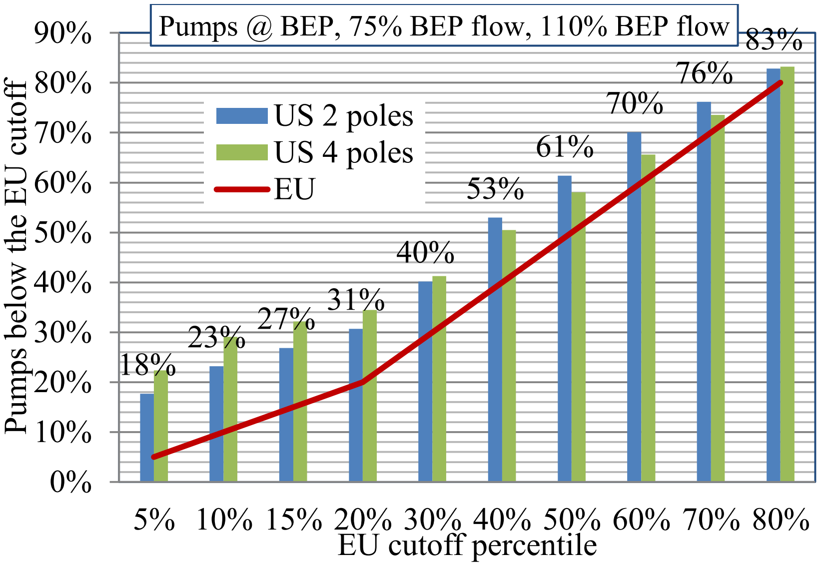
(a)


Pumps @ 75% BEP flow
Pumps below the EU cutoff
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
US 2 poles
US 4 poles
EU
6%
6%
7%
8%
11%
15%
18%
22%
29%
36%
5%
10%
15%
20%
30%
40%
50%
60%
70%
80%
EU cutoff percentile

(b)


Pumps @ 110% BEP flow
Pumps below the EU cutoff
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
US 2 poles
US 4 poles
EU
18%
23%
27%
30%
40%
52%
60%
69%
75%
82%
5%
10%
15%
20%
30%
40%
50%
60%
70%
80%
EU cutoff percentile

(c)



(d)

Note: U.S. percentages shown for 2 pole pumps only.

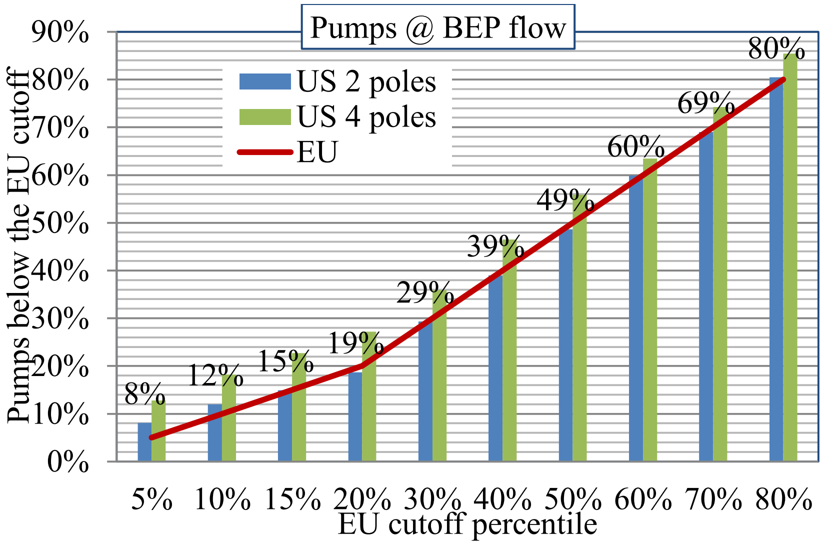
Figure B.1 Comparison of EU MEIs to US Market for ESCC Pumps (a) based on best efficiency point (BEP) only, (b) based on the efficiency at 75% of the BEP flow only, (c) based on the efficiency at 110% of the BEP flow only, and (d) based on the efficiency of BEP, 75% of BEP flow, and 110% of BEP flow

B2. End-Suction Frame Mounted (ESFM) pumps

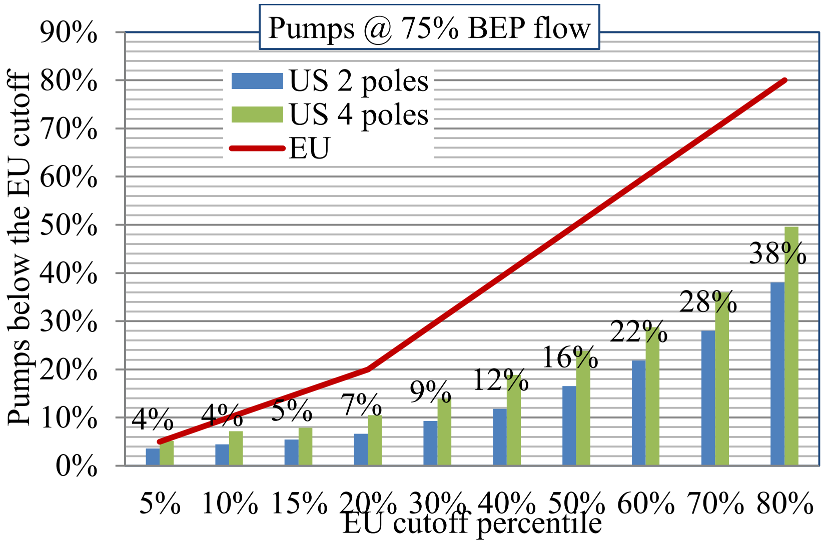
The *C* values for 2-pole and 4-pole ESFM pumps are listed in Table B.2. Figure B.2 compares the ESFM pumps in the U.S. market to various EU MEI standards.

Table B.2 EU Values of *C* for ESFM Pumps

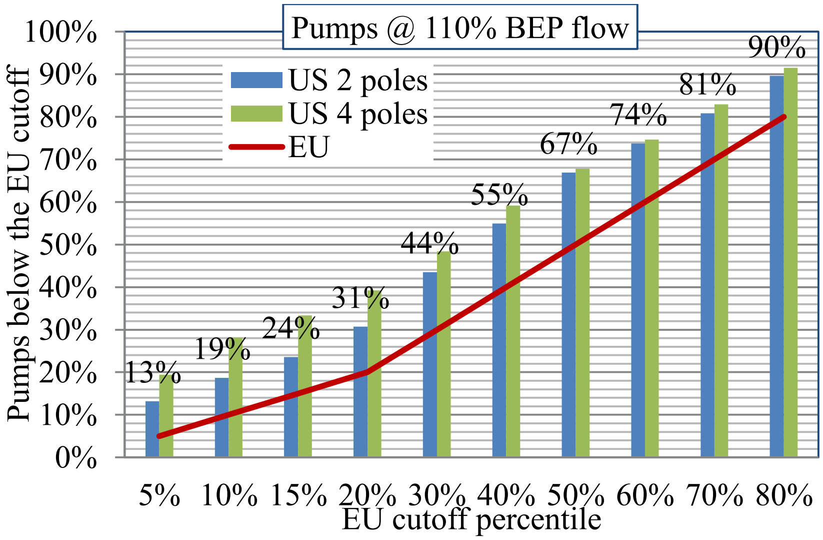
	Quantity cut-off									
C	**5%**	**10%**	**15%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**
ESFM 4 poles	134.38	132.58	131.70	130.68	129.35	128.07	126.97	126.10	124.85	122.94
ESFM 2 poles	137.28	135.60	134.54	133.43	131.61	130.27	129.18	128.12	127.06	125.34


Pumps @ BEP flow
US 2 poles
US 4 poles
EU
Pumps below the EU cutoff
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
8%
12%
15%
19%
29%
39%
49%
60%
69%
80%
5%
10%
15%
20%
30%
40%
50%
60%
70%
80%
EU cutoff percentile

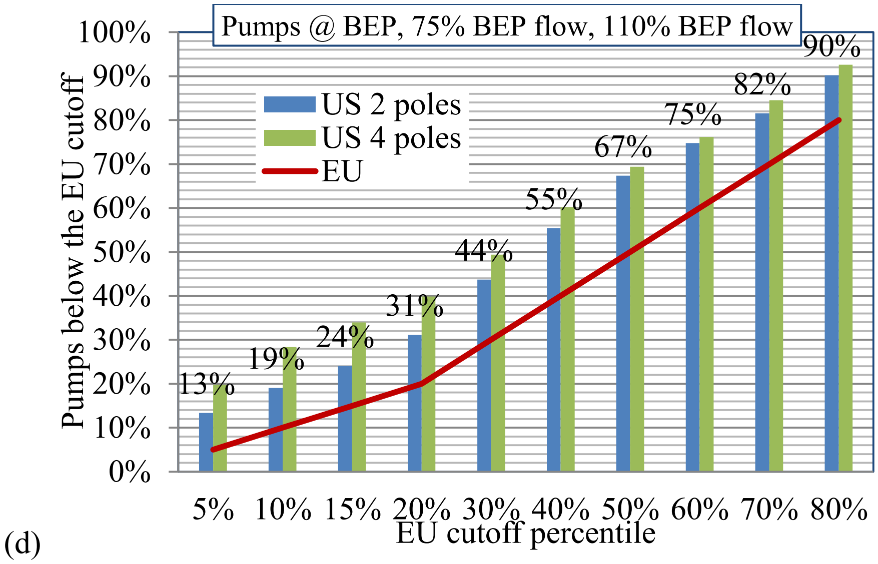
(a)


Pumps @ 75% BEP flow
US 2 poles
US 4 poles
EU
Pumps below the EU cutoff
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
4%
4%
5%
7%
9%
12%
16%
22%
28%
38%
5%
10%
15%
20%
30%
40%
50%
60%
70%
80%
EU cutoff percentile

(b)


Pumps @ 110% BEP flow
US 2 poles
US 4 poles
EU
Pumps below the EU cutoff
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
13%
19%
24%
31%
44%
55%
67%
74%
81%
90%
5%
10%
15%
20%
30%
40%
50%
60%
70%
80%
EU cutoff percentile

(c)



Note: U.S. percentages shown for 2-pole pumps only.

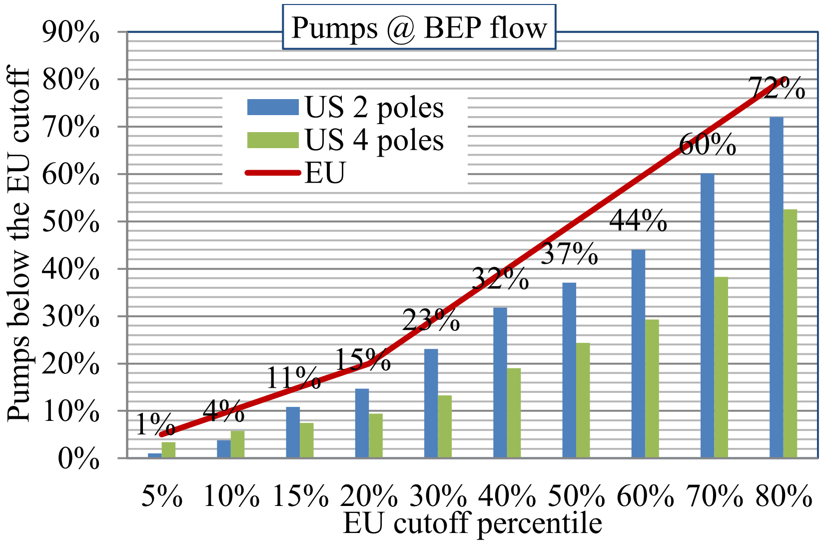
Figure B.2 Comparison of EU MEIs to US Market for ESFM Pumps (a) based on BEP only, (b) based on the efficiency at 75% of the BEP flow only, (c) based on the efficiency at 110% of the BEP flow only, and (d) based on the efficiency of BEP, 75% of BEP flow, and 110% of BEP flow

B3. Vertical Inline (IL) pumps

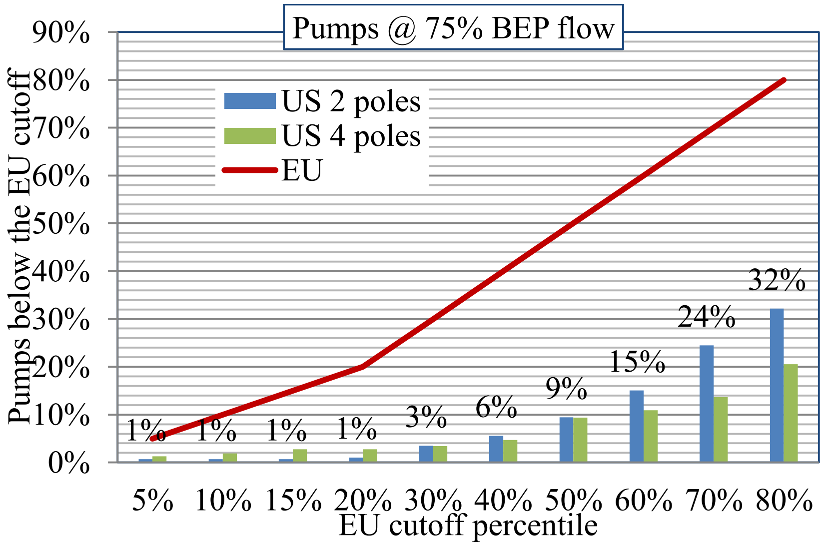
The *C* values for 2-pole and 4-pole IL pumps are listed in Table B.3. Figure B.3 compares the IL pumps in the U.S. market to various EU MEI standards.

Table B.3 EU Values of C for IL Pumps

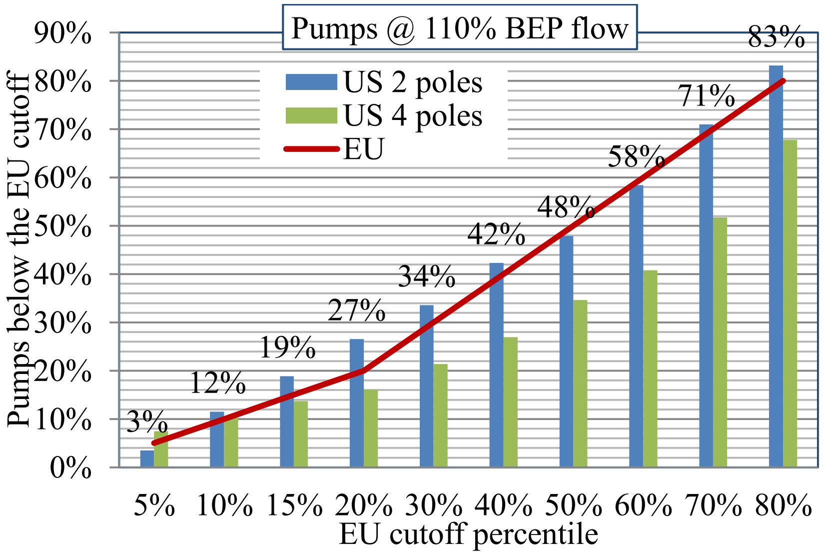
	Quantity cut-off									
C	**5%**	**10%**	**15%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**
ESFM 4 poles	138.13	136.67	135.40	134.60	133.44	132.30	131.00	130.32	128.98	127.30
ESFM 2 poles	141.71	139.45	137.73	136.53	134.91	133.69	132.65	131.34	129.83	128.14


Pumps @ BEP flow
Pumps below the EU cutoff
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
US 2 poles
US 4 poles
EU
1%
4%
11%
15%
23%
32%
37%
44%
60%
72%
5%
10%
15%
20%
30%
40%
50%
60%
70%
80%
EU cutoff percentile

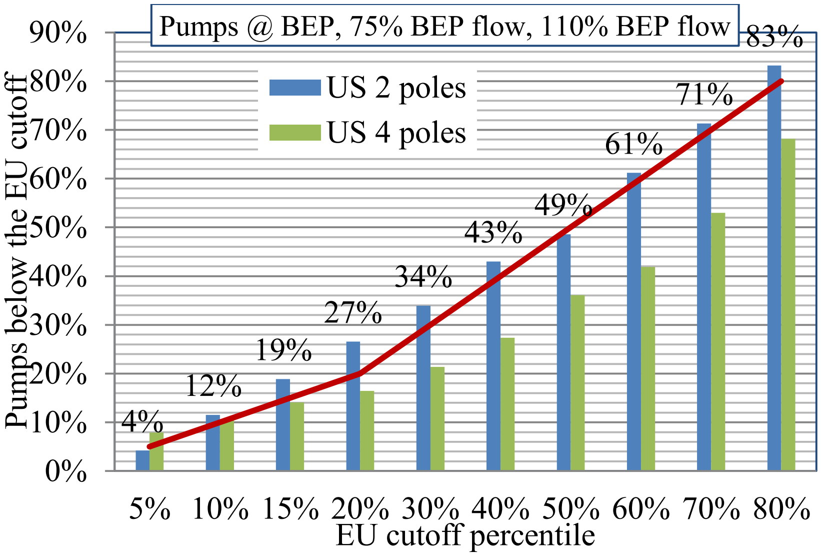
(a)


Pumps @ 75% BEP flow
Pumps below the EU cutoff
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
US 2 poles
US 4 poles
EU
1%
1%
1%
1%
3%
6%
9%
15%
24%
32%
5%
10%
15%
20%
30%
40%
50%
60%
70%
80%
EU cutoff percentile

(b)


Pumps @ 110% BEP flow
Pumps below the EU cutoff
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
US 2 poles
US 4 poles
EU
3%
12%
19%
27%
34%
42%
48%
58%
71%
83%
5%
10%
15%
20%
30%
40%
50%
60%
70%
80%
EU cutoff percentile

(c)



(d)

Note: U.S. percentages shown for 2 pole pumps only.

Figure B.3 Comparison of EU MEIs to U.S. Market for IL Pumps
(a) based on BEP only, (b) based on the efficiency at 75% of the BEP flow only, (c) based on the efficiency at 110% of the BEP flow only, and (d) based on the efficiency of BEP, 75% of BEP flow, and 110% of BEP flow

APPENDIX C - DOE EFFICIENCY SURFACE METHODOLOGY

As mentioned previously, the EU sets minimum efficiency levels using an equation of the following form:

$$\eta_{\mathrm{BEP}} = a\,(\ln Q)^2 + b\,(\ln Q \cdot \ln Ns) + c\,(\ln Ns)^2 + d\,\ln Q + e\,\ln Ns + f$$

Where:

Q is flow (gpm), and
Ns is specific speed (Speed (rpm)×[Flow (gpm)]$^{1/2}$/[Head per stage (ft)]$^{3/4}$).

In order to allow for a flattening of the surface from the bottom to the top of the market, DOE explored using the EU equation but adjusting more coefficients than simply the intercept (*f*). DOE used the 2,316 ESCC pumps with efficiency data for the exploration.

C1. Example Surface Development for All ESCC Pumps

DOE first developed the average surface using a standard regression. DOE then created the top-of-market surface by moving the average surface up by 6 percentiles (at the maximum flow) to 44 percentiles (at the minimum flow). Finally, DOE created the bottom-of-market surface by moving the average surface down by 13 percentiles at the maximum flow and specific speed and 42 percentiles more and 10 percentiles more at the minimum flow and specific speed, respectively.

Coefficients used to create top-of-market, average, and bottom-of-market surfaces are shown in Table C.1. These coefficients and surfaces are simply meant to demonstrate the range of efficiencies available on the market and to show a potential methodology of efficiency surface development that can be adjusted according to the needs of the rulemaking.

Table C.1 DOE Coefficients of Efficiency Surfaces for ESCC Pumps

Coefficients	***a***	***b***	***c***	***d***	***e***	***f***
Top of Market (Blue)	-1.303	3.915	-8.606	-11.324	109.402	-303.181
Average (Green)	-1.303	3.915	-8.606	-6.945	109.402	-347.181
Bottom of Market (Red)	-1.303	3.915	-8.606	-2.105	110.569	-412.181

*Note: There are 2 pumps below the bottom, and 2 pumps above the top.

Figure C.1 shows the fitted average efficiency surface of ESCC pumps at BEP (wireframe in Green), top-of-market efficiency surface (wireframe in Red), and bottom-of-market efficiency surface (wireframe in Blue). Figure C.2 shows the fitted average (Green), top-of-market (Blue), and bottom-of-market (Red) efficiency versus flow lines of ESCC pumps at BEP between various specific speeds. The scatter points in Figure C.2 are ESCC pumps falling in the specific speed range at BEP, and points are colored by pumps' applications in order to show that the development of surfaces would be affected by the exact definition of clean water pumps.[43]

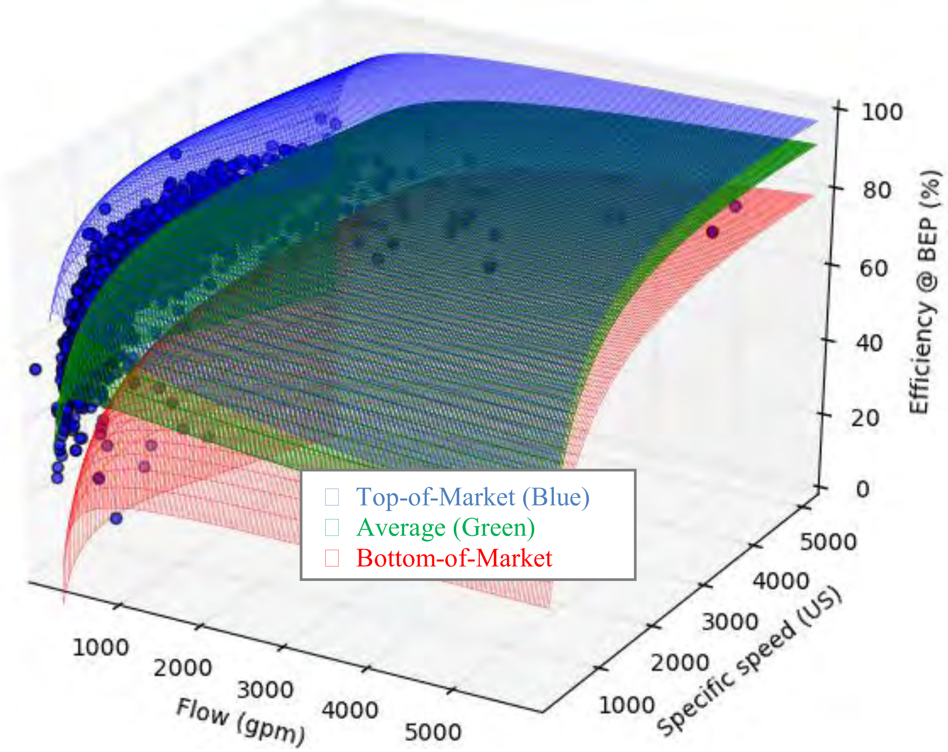
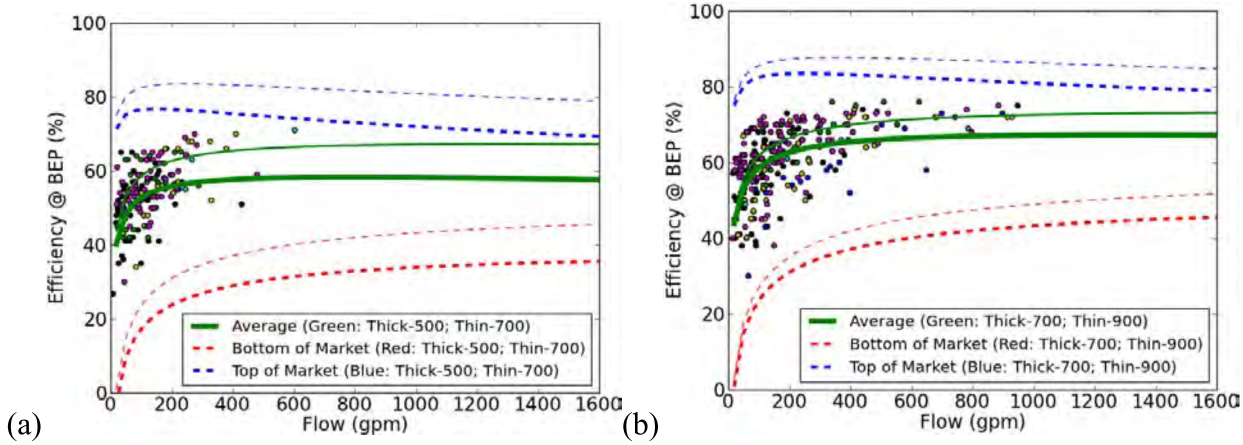


Figure C.1 Average, Top-of-Market, and Bottom-of-Market Efficiency Surfaces for ESCC Pumps



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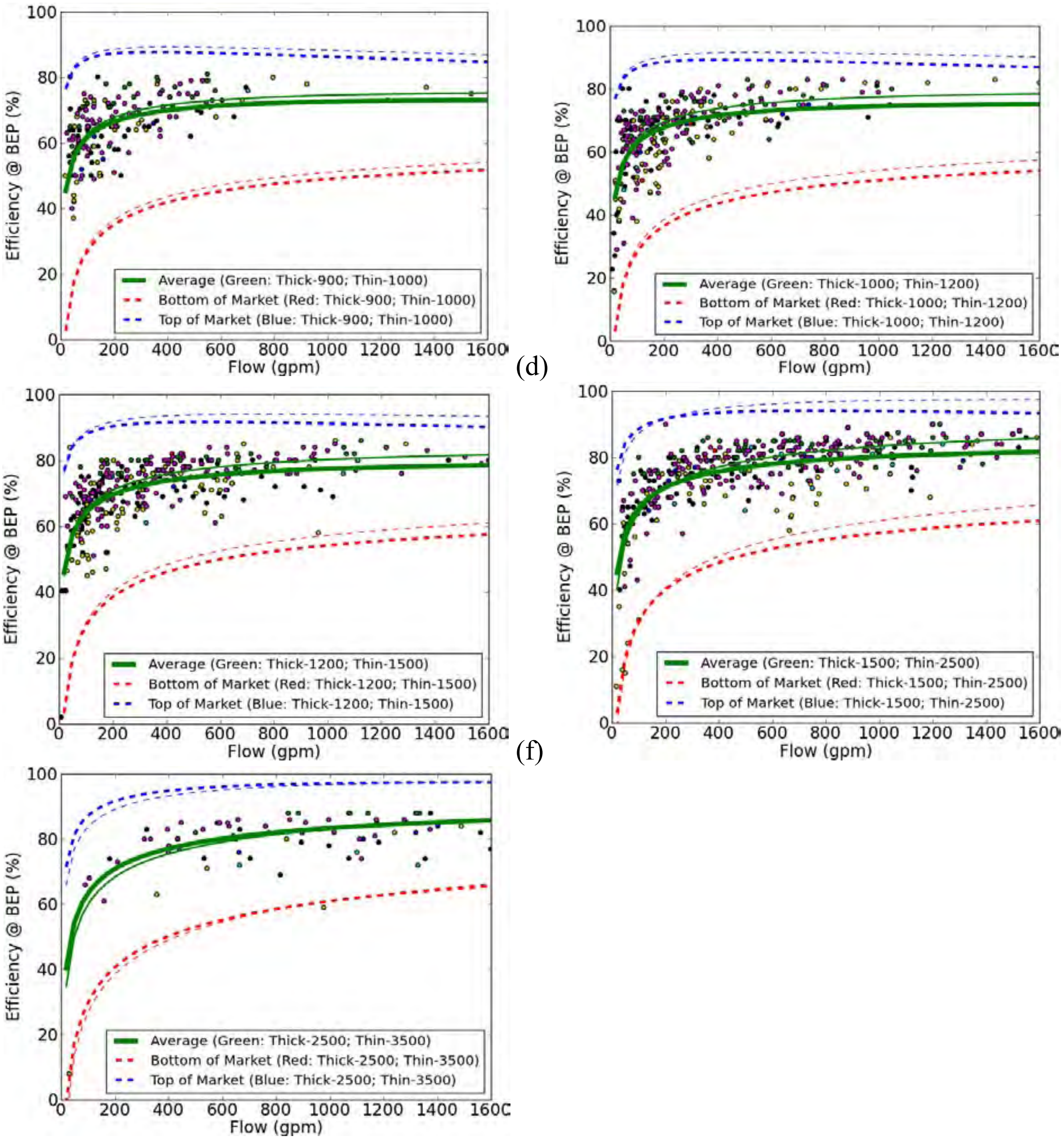
[43] DOE has already filtered all clear wastewater and sealless pumps from its database; the remaining pumps are questionable in terms of whether they will be covered.

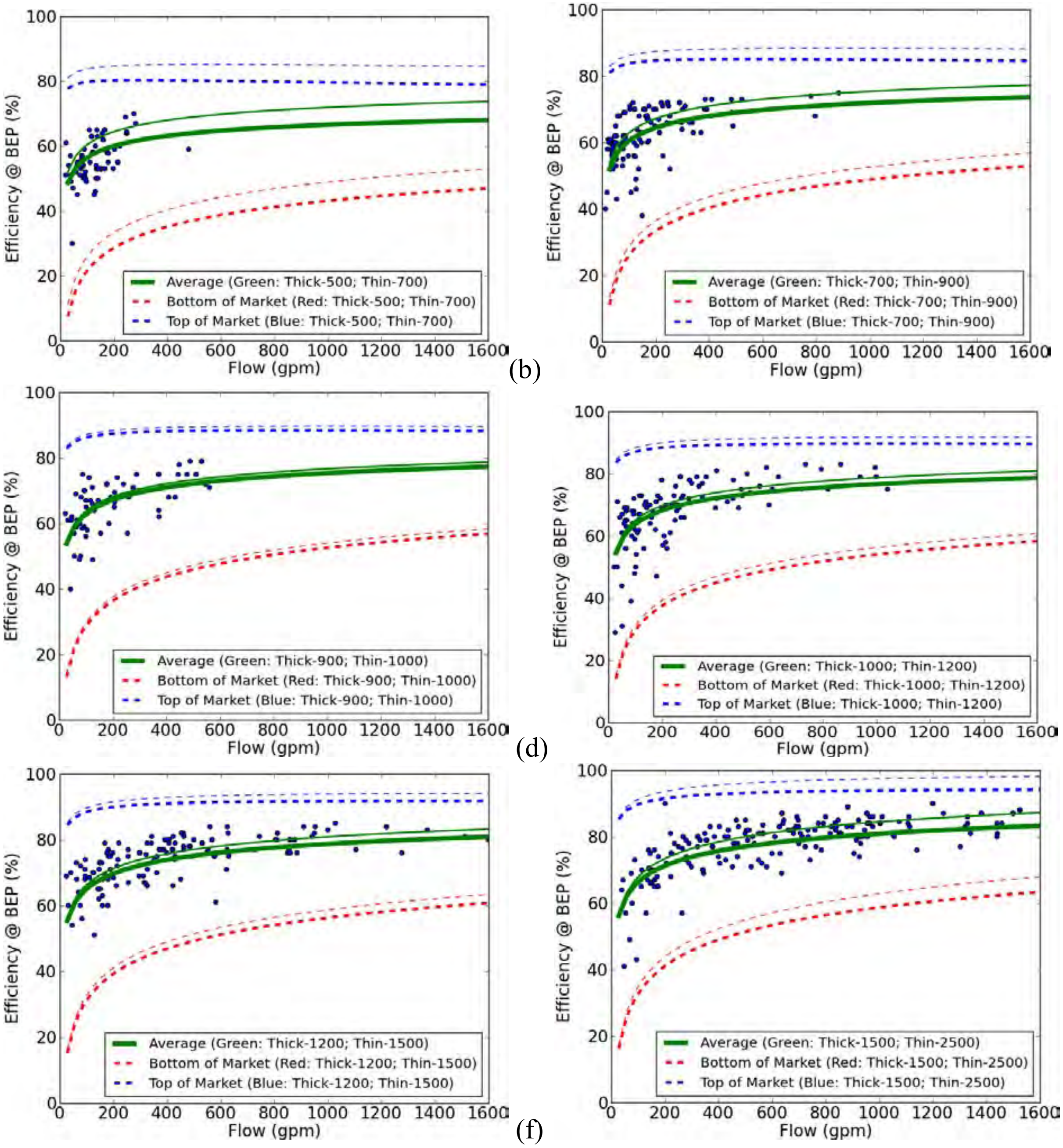


(c) (d) (e) (f) (g)

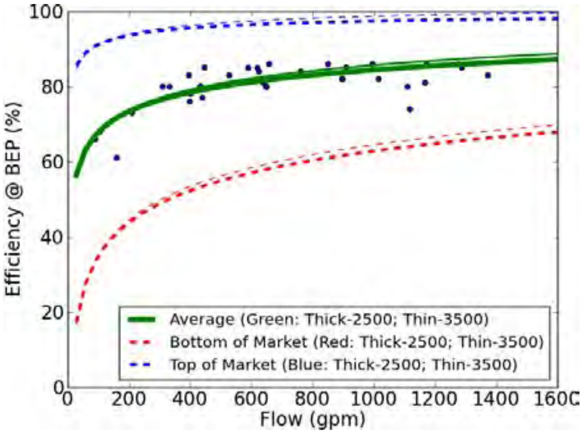
Figure C.2 Specific Speed "Slices" Showing Average, Top-of-Market, and Bottom-of-Market Efficiency Surfaces for ESCC Pumps
(a) Ns = 500-700 (b) Ns = 700-900 (c) Ns = 900-1000 (d) Ns = 1000-1200 (e) Ns = 1200-1500 (f) Ns = 1500-2500 (g) Ns = 2500-3500. Chemical Pumps in Blue, Pumps without Enough Info in Yellow, Refrigerant Pumps in Cyan, Sanitary Pumps in Green, Waste Water Pumps in Purple, Water Pumps in Black, and Water Only pumps in Red.

C2. Water-Only Pumps

DOE also developed similar surfaces fitted with only pumps that DOE can confirm are for water-only applications. Figure C.3 shows the fitted average (Green), top-of-market (Blue), and bottom-of-market (Red) efficiency versus flow lines of confirmed water-only ESCC pumps at BEP between various specific speeds.



(a) (b) (c) (d) (e) (f)

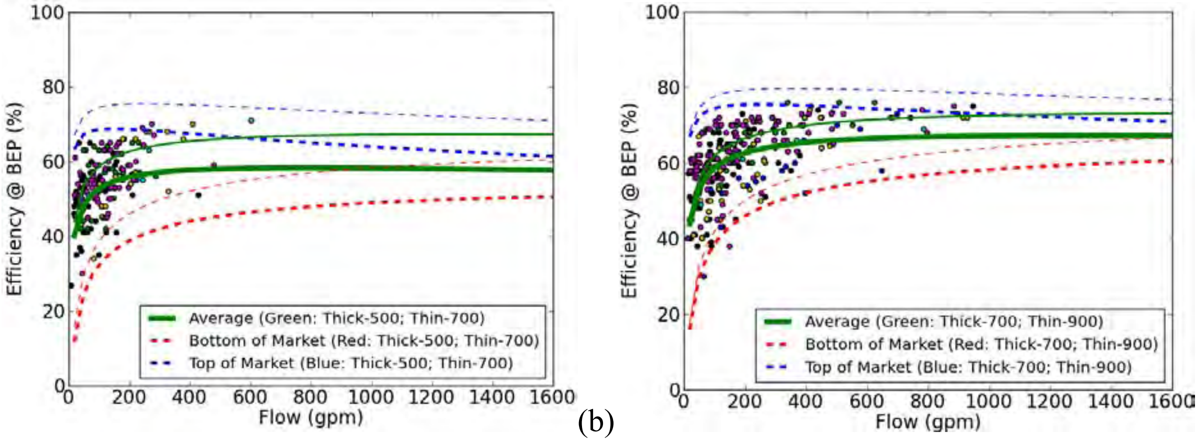


(g)

Figure C.3 Specific Speed "Slices" Showing Average, Top-of-Market, and Bottom-of-Market Efficiency Surfaces for Water-Only ESCC Pumps
(a) Ns = 500-700 (b) Ns = 700-900 (c) Ns = 900-1000 (d) Ns = 1000-1200 (e) Ns = 1200-1500 (f) Ns = 1500-2500 (g) Ns = 2500-3500.

C3. Baseline and Market Maximum Levels

As discussed in the engineering analysis section, DOE must develop baseline and market maximum efficiency levels that may be different from the bottom-of-market and top-of-market efficiency levels, respectively. These levels must be fairly representative in all areas, covering many pumps over a wide range of flow and specific speed. Figure C.4 shows an example of this approach, in which the bottom of market has been moved up by 15 percentiles to better represent a possible baseline, and the top of market has been moved down by 8 percentiles, to better represent market maximum. Figure C.4 shows the average (Green), moved top-of-market (Blue), and moved bottom-of-market (Red) efficiency versus flow lines of ESCC pumps at BEP between various specific speeds. The scatter points in Figure C.4 are ESCC pumps falling in the specific speed range at BEP, and the points are colored by pump application.



(a) (b)

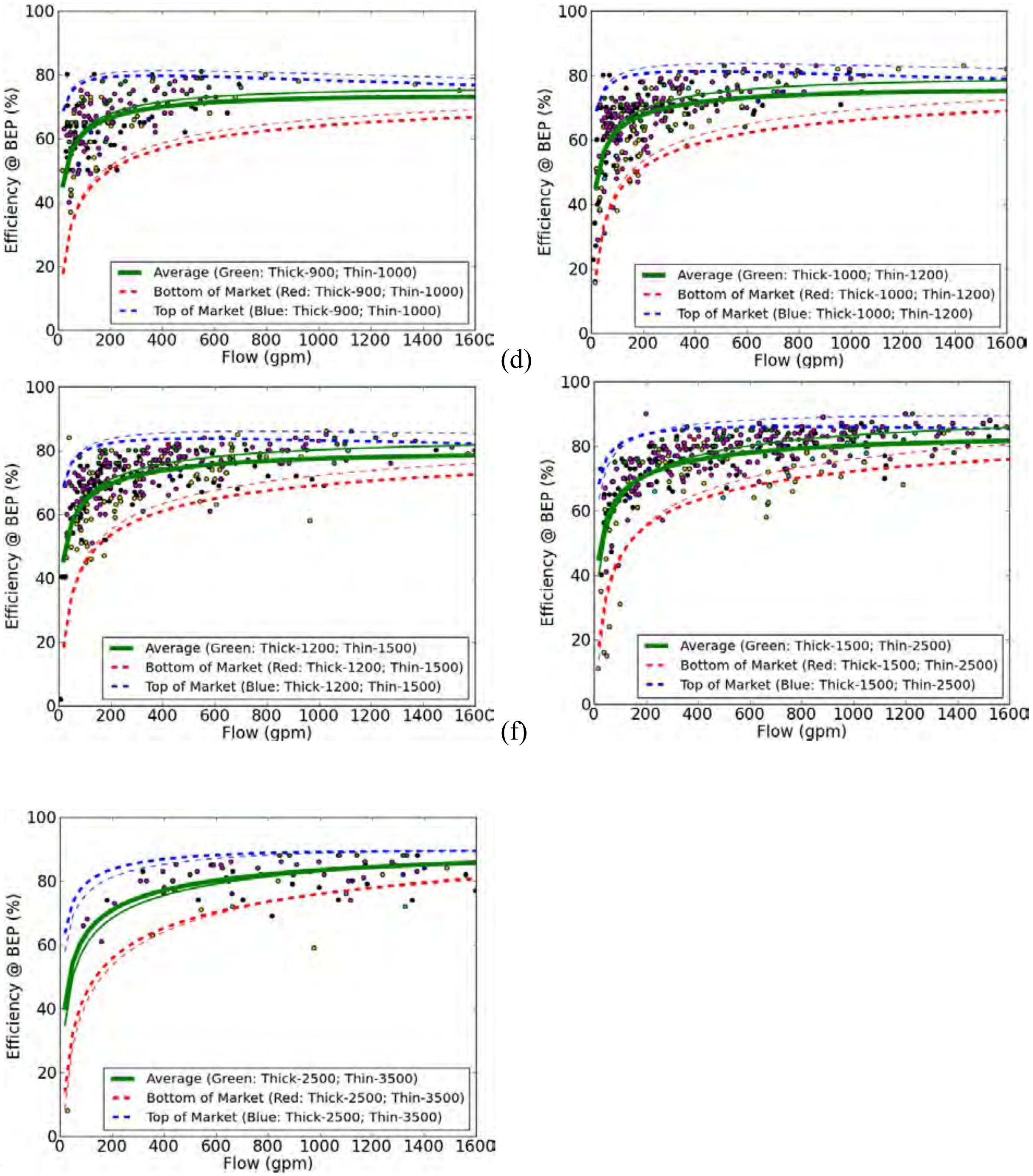


Figure C.4 Specific Speed "Slices" Showing Potential Average, Baseline, and Market Maximum Efficiency Surfaces for ESCC Pumps
(a) Ns = 500-700 (b) Ns = 700-900 (c) Ns = 900-1000 (d) Ns = 1000-1200 (e) Ns = 1200-1500 (f) Ns = 1500-2500 (g) Ns = 2500-3500. Chemical Pumps in Blue, Pumps without Enough Info in Yellow, Refrigerant Pumps in Cyan, Sanitary Pumps in Green, Waste Water Pumps in Purple, Water Pumps in Black, and Water Only pumps in Red.

APPENDIX D - PUMP DESIGN SPEED

This appendix provides more details regarding the differences in pump efficiency curves due to design speed. Two different approaches are applied: one with varying intercept values in the efficiency curve formulation, while keeping all other coefficients the same; and the other with constant intercept values while changing other coefficients in the efficiency model. The former one corresponds to a vertical change in the efficiency surface, as in EU's methodology, and the latter one corresponds to a surface shape change.

DOE also explores how the results of this modeling change when narrowing the pump scope to a more limited clean water-only set.

D1. Varying Intercept Approach (Vertical Change in Surface)

The efficiency is modeled as a function of specific speed (Ns) and flow (Q):

$$\eta = a\,(\ln Q)^2 + b\ \ \ln Q\ \cdot \ln Ns\ + c\ \ \ln Ns\ ^{2} + d \ln Q + e \ln Ns + f$$

In the vertical change (varying intercept) approach, coefficient f varies for different numbers of poles, while the other five coefficients stay the same.

D1.1. ESCC Pumps

A total of 2,316 ESCC pumps with valid efficiency data are selected from DOE's PUMP-FLO database. The distribution of number of poles is shown in Table D.1.

Table D.1 Distribution of Number of Poles for ESCC Pumps

Number of Poles	ESCC Pumps	
	Freq.	**Percent**
2	759	32.77%
4	1,168	50.43%
6	321	13.86%
8	30	1.30%
Total	2316	98.36%

Different model formulations are considered with the results summarized in Table D.2. Model 1 is the base line with no consideration of design speed. Model 3 takes into account the intercept differences, *Δf,* for pumps with 2-pole, 4-pole, 6-pole, and 8-pole motors, respectively. However, the *Δf*s for 4-pole and 6-pole are not statistically significant at α = 0.05 (95% confidence). So in Model 2 DOE dropped *Δf* for 6-pole, which resulted in the highlighted model that has all statistically significant coefficients and a better model fit (higher adjusted R^2 value). According to the model results, pumps with 4-pole motors translate into a 2.16 increase in efficiency, compared to pumps with 2-pole motors. Pumps with 6-pole motors have a 1.43 increase compared to 4-pole motors, and pumps with 8-pole motors have a 4.81 increase compared to 6-pole motors. This makes the total efficiency spread between 2-pole and 8-pole motors 8.4. The coefficients from Model 2 are summarized in Table D.3, while the efficiency surfaces are plotted in Figure D.1.

Table D.2 Models with Vertical Change in Surface for ESCC Pumps

	Model 1		**Model 2**		**Model 3**	
η	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**
a	-1.30*	0.12	-1.44*	0.12	-1.45*	0.12
b	3.92*	0.50	3.99*	0.49	4.01*	0.49
c	-8.61*	0.71	-8.71*	0.69	-8.72*	0.70
d	-6.95*	2.89	-6.00*	2.83	-6.07*	2.84
e	109.42*	8.29	110.15*	8.13	110.31*	8.15
f	-347.23*	25.59	-349.38*	25.07	-349.43*	25.08
2-pole Δf			-3.59*	0.45	-3.92*	1.19
4-pole Δf			-1.43*	0.42	-1.75	1.17
6-pole Δf					-0.35	1.21
8-pole Δf			4.81*	1.32	4.49*	1.72
R^2		**0.6962**		**0.7094**		**0.7094**
Adjusted R^2		**0.6956**		**0.7084**		**0.7082**

*: statistically significant at 0.05

Table D.3 Coefficients from Model 2 with Vertical Change in Surface for ESCC Pumps

η	**Base**	**2-pole**	**4-pole**	**6-pole^**	**8-pole**	**Weighted Average**
a	-1.44	-1.44	-1.44	-1.44	-1.44	-1.44
b	3.99	3.99	3.99	3.99	3.99	3.99
c	-8.71	-8.71	-8.71	-8.71	-8.71	-8.71
d	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00
e	110.15	110.15	110.15	110.15	110.15	110.15
f	-349.38	-352.97	-350.82	-349.38	-344.57	-351.22

^: 6-pole coefficients are equivalent to the base coefficients because 6-pole pumps were removed from the model.

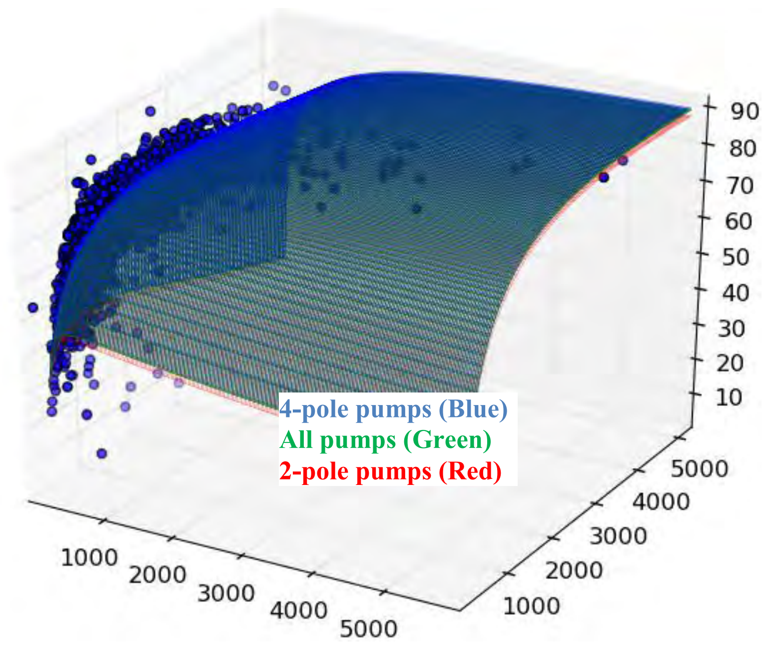


Figure D.1 Efficiency Surfaces Using Model 2 with Vertical Change in Surface for All Pumps

D1.2. End Suction Frame Mounted (ESFM) Pumps

A total of 4,222 ESFM pumps are selected from DOE’s PUMP-FLO database. The distribution of number of poles is shown in Table D.4.

Table D.4 Distribution of Number of Poles for ESFM Pumps

Number of Poles	Freq.	Percent
2	1,106	26%
4	1,877	44%
6	828	20%
8	220	5%
10	5	0%
12	1	0%
Total	4222	100%

For ESFM, the model used included *Δf* for all poles, as all coefficients were statistically significant. The coefficients are summarized in Table D.5, while the efficiency surfaces are plotted in Figure D.2. The average difference between 4-pole and 2-pole pumps is 1.6 efficiency points. All coefficients are statistically significant at the 0.10 level (90% confidence). This is slightly less confident than the ones for ESCC, which are at a 0.05 level (95% confidence), but still acceptable.

Table D.5 Coefficients for ESFM Pump Model

η	Base	2-pole	4-pole	6-pole	8-pole	Weighted

						Average
a	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02
b	1.43	1.43	1.43	1.43	1.43	1.43
c	-7.52	-7.52	-7.52	-7.52	-7.52	-7.52
d	6.53	6.53	6.53	6.53	6.53	6.53
e	109.68	109.68	109.68	109.68	109.68	109.68
f	-390.03	-390.97	-389.32	-388.96	-389.01	-389.70

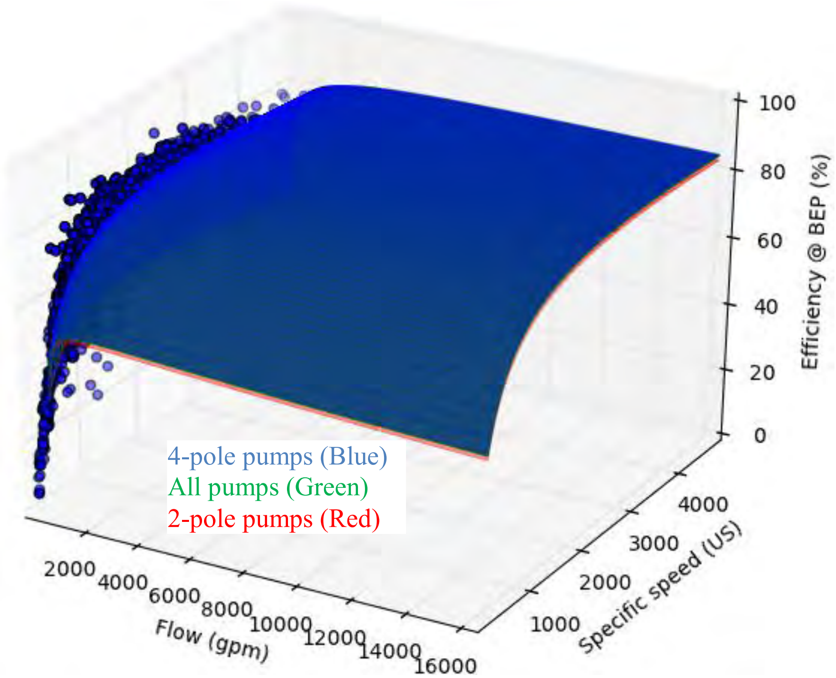


Figure D.2 Efficiency Surfaces of ESFM pumps with 2 and 4 poles

D1.3. Inline (IL) Pumps

A total of 963 IL pumps are selected from DOE's PUMP-FLO database. The distribution of number of poles is shown in Table D.6.

Table D.6 Distribution of Number of Poles for IL Pumps

Number of Poles	Freq.	Percent
2	286	30%
4	468	49%
6	200	21%
8	9	1%
Total	963	100%

For IL, the best model fit dropped Δf for 6-pole and 8-pole pumps. The coefficients are summarized in Table D.7, while the efficiency surfaces are plotted in Figure D.3. The average difference between 4-pole and 2-pole pumps is 3.13 efficiency points. All coefficients except for d are statistically significant at a 0.05 level (95% confidence).

Table D.7 Coefficients for IL Pump Model

η	Base	2-pole	4-pole	6-pole	8-pole	Weighted Average
a	-1.32	-1.32	-1.32	-1.32	-1.32	-1.32
b	3.13	3.13	3.13	3.13	3.13	3.13
c	-9.52	-9.52	-9.52	-9.52	-9.52	-9.52
d	-1.86	-1.86	-1.86	-1.86	-1.86	-1.86
e	128.77	128.77	128.77	128.77	128.77	128.77
f	-433.48	-437.67	-434.54	-433.48	-433.48	-435.24

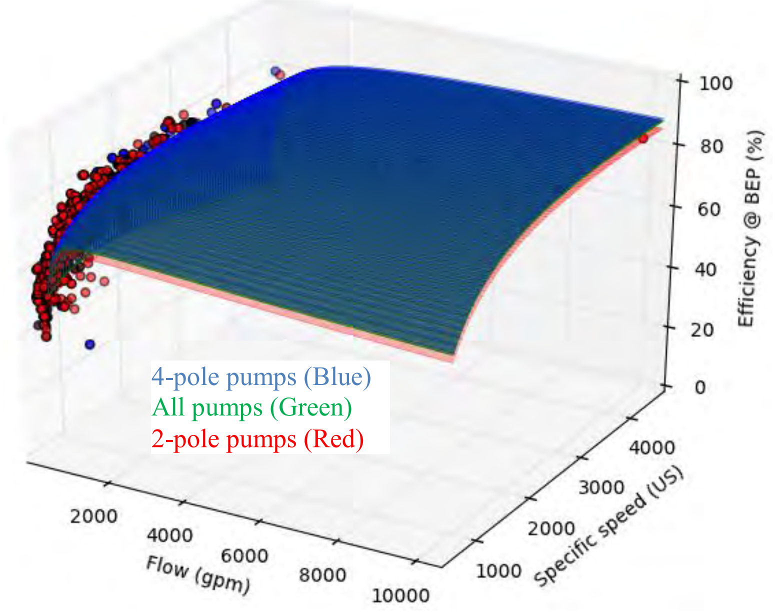


Figure D.3 Efficiency Surfaces of IL Pumps with 2 and 4 poles

D2. Constant Intercept Approach (Surface Shape Change)

DOE also explored a constant intercept approach using ESCC pumps as an example. In the constant intercept approach, coefficients $a - e$ vary for different design speeds, while the intercept f stays constant. Different model formulations are considered with results summarized in Table D.8. Model 5 takes into account the differences $\Delta a - \Delta e$ for pumps with 2-pole, 4-pole, 6-pole, and 8-pole motors, respectively. However, most of the $\Delta a - \Delta e$ for 6-pole and 8-pole are not statistically significant at $\alpha = 0.05$ (95% confidence). So in Model 4 DOE dropped $\Delta a - \Delta e$ for 6-pole and 8-pole, which resulted in the highlighted model that has mostly statistically significant coefficients. Depending on the specific speed and flow at Best Efficiency Point (BEP), the differences between 2-pole and 4-pole could be positive or negative, which makes it difficult to interpret the relative efficiencies. The coefficients from Model 4 are summarized in Table D.9, while the efficiency surfaces are plotted in Figure D.4.

Table D.8 Models with Surface Shape Change for All ESCC Pumps

	Model 1		**Model 4**		**Model 5**	
η	Coefficient	Std. Err.	Coefficient	Std. Err.	Coefficient	Std. Err.
a	-1.30*	0.12	1.03*	0.32	1.92	1.99
b	3.92*	0.50	-6.34*	1.27	-2.95	5.80
c	-8.61*	0.71	-1.79	1.11	-5.92	4.26
d	-6.95*	2.89	38.57*	7.08	-0.05*	25.06
e	109.42*	8.29	72.52*	9.87	109.20*	25.75
f	-347.23*	25.59	-347.68*	24.94	-344.56*	25.20
2-pole Δa			-3.26*	0.42	-4.15*	2.01
2-pole Δb			15.28*	1.59	11.85*	5.86
2-pole Δc			-10.06*	1.12	-5.84	4.21
2-pole Δd			-71.26*	8.96	-32.47	25.56
2-pole Δe			56.07*	7.24	18.38	24.22
4-pole Δa			-2.57*	0.35	-3.46	2.00
4-pole Δb			10.47*	1.38	7.06	5.81
4-pole Δc			-6.91*	0.99	-2.70	4.18
4-pole Δd			-44.25*	7.74	-5.54	25.20
4-pole Δe			36.57*	6.38	-1.05	24.02
6-pole Δa					-0.79	2.05
6-pole Δb					-3.92	6.02
6-pole Δc					4.51	4.31
6-pole Δd					42.34	26.40
6-pole Δe					-40.20	24.85
8-pole Δa					2.88	2.54
8-pole Δb					-16.48	8.92
8-pole Δc					12.28	6.35
8-pole Δd					92.75*	47.18
8-pole Δe					-81.42*	39.51
R^2		**0.6962**		**0.7221**		**0.7247**

	Model 1		Model 4		Model 5	
η	Coefficient	Std. Err.	Coefficient	Std. Err.	Coefficient	Std. Err.
Adjusted R^2		**0.6956**		**0.7203**		**0.7217**

*: statistically significant at 0.05

Table D.9 Coefficients from Model 4 with Surface Shape Change for ESCC Pumps

η	**Base**	**2-pole**	**4-pole**	**Weighted Average**
a	1.03	-2.23	-1.54	-1.34
b	-6.34	8.93	4.13	3.94
c	-1.79	-11.85	-8.70	-8.57
d	38.57	-32.69	-5.69	-7.10
e	72.52	128.60	109.09	109.34
f	-347.68	-347.68	-347.68	-347.68

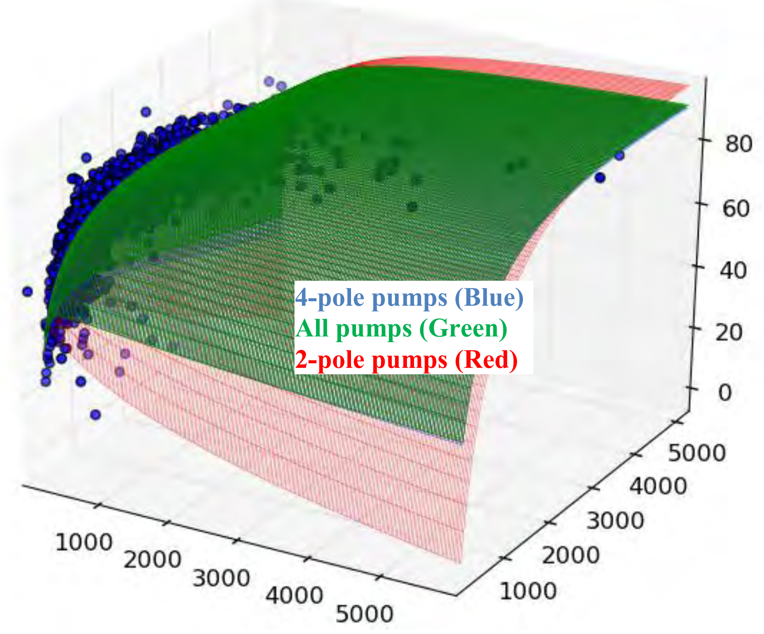


Figure D.4 Efficiency Surfaces Using Model 4 with Surface Shape Change for ESCC Pumps

D3. Effects of Pump Scope

For ESCC pumps, DOE also explored the effect of using a more limited set of pumps from the database – namely, the 973 ESCC pumps for which DOE can confirm that the pumps are designed for water-only applications. Table D.10 shows the distribution of number of poles for these pumps.

Table D.10 Distribution of Number of Poles for ESCC Water-Only Pumps

Number of Poles	**Water-only Pumps**

	Freq.	Percent
2	290	29.80%
4	512	52.62%
6	165	16.96%
8	5	0.51%
Total	973	99.90%

DOE only used the vertical change approach for this analysis because of the difficulty in interpreting the results of the surface shape change approach. For ESCC water-only pumps, the best model fit excluded Δf for 4-pole, 6-pole, and 8-pole pumps. According to the model results, pumps with 4-pole motors translate into a 1.83 increase in efficiency, compared to pumps with 2-pole motors. This difference is slightly lower than that of 2.16 obtained using the broader set of ESCC pumps in the database. The coefficients from the model are summarized in Table D.11, while the efficiency surfaces are plotted in Figure D.5.

Table D.11 Coefficients for Water-Only Pumps

η	Base	2-pole	4-pole^	6-pole^	8-pole^	Weighted Average
a	-0.58	-0.58	-0.58	-0.58	-0.58	-0.58
b	1.79	1.79	1.79	1.79	1.79	1.79
c	-3.76	-3.76	-3.76	-3.76	-3.76	-3.76
d	-0.24	-0.24	-0.24	-0.24	-0.24	-0.24
e	51.56	51.56	51.56	51.56	51.56	51.56
f	-155.94	-157.77	-155.94	-155.94	-155.94	-156.49

^: coefficients are equivalent to the base coefficients because these pumps were removed from the model.

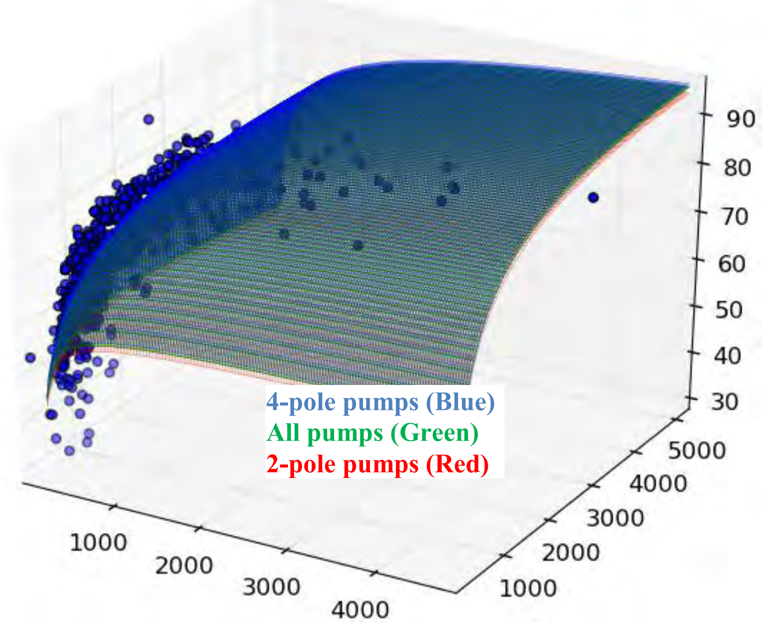


Figure D.5 Efficiency Surfaces for Water-only Pumps

D4. Results

In general, the approach with surface shape change yields a better model fit than the vertical change in surface approach, though the model fit improvement is very small. In addition, depending on the specific speed and flow at BEP, the differences between 2-pole and 4-pole in the surface shape change model could be positive or negative, which makes it difficult to interpret the relative efficiencies.

In the vertical change approach on average, ESCC pumps with 4-pole motors show an increase of 2.16 in efficiency compared to ESCC pumps with 2-pole motors (at constant Ns and flow). This is slightly less than the EU difference between 4-pole and 2-pole pumps at MEI 50, which is 2.5. Similarly, ESFM pumps with 4-pole motors show an increase of 1.64 compared to ESFM pumps with 2-pole motors (at constant Ns and flow), and IL pumps show an increase of 3.13 compared to IL pumps with 2-pole motors (at constant Ns and flow).

The analysis was also conducted on water-only ESCC pumps, which suggested statistically significant differences in efficiency between pumps with 2-pole motors and other pumps of 1.83. This difference is slightly lower than that of 2.16 using the broader set of ESCC pumps in the database

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