CHAPTER 4. SCREENING ANALYSIS

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4.1 INTRODUCTION

This chapter details the screening analysis that the U.S. Department of Energy (DOE) conducted in support of the ongoing energy conservation standards rulemaking for residential water heaters, direct heating equipment (DHE), and pool heaters.

In the market and technology assessment (MTA; chapter 3), DOE presents an initial list of technologies manufacturers can use to improve the energy efficiency of residential water heaters, DHE, and pool heaters. The purpose of the screening analysis is to evaluate the technologies that improve product energy efficiency to determine which technologies DOE should consider further in the rulemaking analyses. DOE consulted a range of parties, including industry and technical experts and others, to develop a list of technologies for consideration. Some of these technologies can reduce annual energy consumption of products in actual applications, but may not improve the energy factor (EF), the annual fuel utilization efficiency (AFUE), or the thermal efficiency of water heaters, DHE, and pool heaters, respectively. The EF of water heaters is measured using DOE's test procedure specified in 10 Code of Federal Regulations (CFR) section 430 Subpart B, Appendix E, *Uniform Test Method for Measuring the Energy Consumption of Water Heaters*. The AFUE of DHE is measured using DOE's test procedure specified in 10 CFR 430 Subpart B, Appendix O, *Uniform Test Method for Measuring the Energy Consumption of Vented Home Heating Equipment*. The thermal efficiency of pool heaters is measured by the American National Standards Institute (ANSI) *Standard for Gas-Fired Pool Heaters* (ANSI Z21.65-1994), which DOE has incorporated by reference into its regulations at 10 CFR 430 Subpart B, Appendix P. DOE removed from consideration those technologies that do not increase EF, AFUE, or thermal efficiency per these test procedures. DOE evaluated the remaining technologies pursuant to the criteria in The Energy Policy and Conservation Act (EPCA), as amended. (42 U.S.C. 6311-6317)

Section 325(o) of EPCA establishes criteria for prescribing new or amended standards designed to achieve the maximum improvement in energy efficiency. Furthermore, EPCA directs the Secretary of Energy to determine whether a standard is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)(B)) In view of this requirement, 10 CFR part 430, subpart C, appendix A, 4(a)(4) and 5(b) guides DOE in its consideration and promulgation of new or revised product efficiency standards. These procedures elaborate on the statutory criteria provided in 42 U.S.C. 6295(o) and, in part, eliminate problematic technologies early in the process of prescribing or amending an energy efficiency standard. In particular, DOE determines whether to eliminate from consideration any technology that presents unacceptable problems with respect to the following criteria:

Technological feasibility. If it is determined a technology has not been incorporated into residential products or in working prototypes, then the technology will not be considered further.

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

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

Safety of technologies. If it is determined a technology will have significant adverse impacts on health or safety, it will not be considered further.

In sum, if DOE determines that a technology, or a combination of technologies do not meet the four criteria above it will be eliminated from consideration. If a particular technology fails to meet one or more of the four criteria, it will be screened out. The reasons for eliminating any technology are documented in section 4.2.

4.2 SCREENED-OUT TECHNOLOGIES

This section describes the technologies that DOE eliminated for failure to meet one of the following four factors: 1) technological feasibility; 2) practicability to manufacture, install, and service; 3) impacts on equipment utility to consumers; or 4) consumer health or safety.

4.2.1 Water Heaters

DOE eliminated the following technology options for residential water heaters from further consideration: side-arm heater, flue damper (buoyancy operated), directly fired, condensing pulse combustion, advanced forms of insulation, thermophotovoltaic and thermoelectric generators, U-tube flue, reduced burner size (slow recovery), two-phase thermosiphon (TPTS), and CO_2 heat pump water heater.

4.2.1.1 Side-Arm Heater (Gas and Oil Storage)

Side-arm heaters circulate the potable water between the tank and an external heat exchanger, typically a shell-in-tube exchanger. The side-arm heater design avoids large flue losses by removing the flue from the center of the gas- or oil-fired storage tank.

Side-arm storage water heaters are not commercially available, although products incorporating side-arm heaters have been commercially available in small quantities. However, DOE was not been able to identify a current working prototype for gas or oil-fired storage water heaters, and believes manufacturers no longer use this technology. Therefore, it is not technologically feasible and not practical to manufacture, install, and service side-arm storage water heaters on the scale necessary to serve the relevant market at the time of the effective date of the standard.

4.2.1.2 Flue Damper (Buoyancy Operated) (Gas Storage)

This flue damper is a small, very lightweight aluminum dome-shaped poppet that is lifted by the buoyancy of the combustion products to allow flue gases to enter the venting system. This technology option would reduce off-cycle standby losses by sealing the flue and preventing convection to the venting system, but would have no effect on recovery efficiency because it does not affect the rate of heat transfer. This flue damper may not work with high-recovery efficiency water heaters because there may not be enough waste heat in the combustion products to provide sufficient buoyancy to lift the poppet.

Safety concerns exist because the damper may not open due to the low energy of the combustion products. If the flue is blocked, safety interlocks should prevent the gas storage water heater from operating. Otherwise, harmful combustion products will enter the space where the water heater is installed (*i.e.*, residence). Although safety interlocks can mitigate improper exhaustion, the water heater would still be inoperable. Therefore, DOE does not consider buoyancy operated flue dampers for gas-fired storage water heaters a means to improve EF due to the adverse impacts on safety.

4.2.1.3 Directly Fired (Gas and Oil Storage)

A directly fired gas- or oil-fired storage water heater uses a direct contact heat exchange process that puts potable water directly into contact with the burner flame and flue products. Spraying the water directly at the flame is a more efficient means of transferring heat than in a conventional shell-and-tube heat exchanger because the heat-resistive barrier between the water and the flue products is eliminated. However, this can also lead to contamination of domestic water by the flue products, which can cause health and safety problems for end users. This technology can also conflict with local plumbing codes (*e.g.*, International Association of Professional Plumbing and Mechanical Officials (IAPMO) 1991) with respect to water quality. Therefore, this technology is screened out because of the adverse impacts on health and safety.

4.2.1.4 Condensing Pulse Combustion (Gas, Oil Storage, and Instantaneous)

Pulse combustion burners operate on self-sustaining resonating pressure waves that alternately rarefy the combustion chamber. Pulse combustion systems are capable of self-venting, and can draw outside air for combustion even when installed inside. Pulse combustion technologies can achieve high steady-state efficiencies and condensing operation without the use of fans or blowers.

Prototype gas- and oil-fired storage and instantaneous water heaters incorporating pulse combustion technologies have been developed in the past. However, this technology is not prevalent among commercially available products, or even among water heater research efforts. Although condensing pulse combustion technology shows promising results in increasing EF, it has not yet penetrated the gas-fired storage, oil-fired storage, and instantaneous water heater markets. Therefore, it is not technologically feasible and not practicable to manufacture, install, and service condensing pulse combustion technology on the scale necessary to serve the relevant market at the time of the effective date of the standard.

4.2.1.5 Advanced Forms of Insulation (Gas, Electric, and Oil Storage)

Insulating gas-fired, electric, and oil-fired storage water heaters with vacuum, inert gases, aerogel, or evacuated panels is an alternative to increasing the thickness of the insulation to decrease heat transfer and standby losses. Manufacturers elect to use alternative types of insulation because increasing the thickness of insulation may create shipping and installation problems if diameters exceed standard building clearance widths. However, several factors limit the inclusion of advanced forms of insulation into products today.

To the best of DOE’s knowledge, vacuum insulation technology has not been demonstrated for water heater applications for either production or prototyping. Durability and maintaining the seal over the life of the storage water heater are some problems of vacuum insulation. Although vacuum insulation shows promising potential for increasing EF, no manufacturer has incorporated this technology into a commercially available product. Thus, the reliability over the life of the water heater has not been demonstrated. Therefore, it is not technologically feasible and not practicable to manufacture, install, and service vacuum insulation technology for gas-fired, electric, and oil-fired storage water heaters on the scale necessary to serve the relevant market at the time of the effective date of the standard.

Gas-filled panel technology has not been demonstrated for water heater applications for both production and prototyping, to the best of DOE’s knowledge.[1] Prototypes have been developed for other applications and insulation improvements have been achieved. However, gas-filled panel technology has not yet penetrated the gas-fired, electric, and oil-fired storage water heater markets. Therefore, it is not technologically feasible and not practicable to manufacture, install, and service gas-filled panel technology for gas-fired, electric, and oil-fired storage water heaters on the scale necessary to serve the relevant market at the time of the effective date of the standard.

Aerogel insulation technology has not been demonstrated in any commercially available water heater applications to the best of DOE’s knowledge. Although aerogel insulation shows promising potential for increasing EF, it has not yet penetrated the storage water heater market because manufacturers must first address potential problems. Aerogel insulation is vulnerable to shock and vibration, which may create shipping and installation problems if specific handling techniques are required. In addition, it is hygroscopic and requires thorough sealing within the cavity to prevent exposure to water sources. Therefore, it is not technologically feasible and not practicable to manufacture, install, and service aerogel insulation technology for gas-fired, electric, and oil-fired storage water heaters on the scale necessary to serve the relevant market at the time of the effective date of the standard.

Evacuated-panel technology has not been demonstrated for water heater applications for both production and prototyping, to the best of DOE's knowledge. Prototypes have been developed for other applications and insulation improvements have been achieved. However, evacuated-panel technology has not yet penetrated the gas-fired, electric, and oil-fired storage water heater markets. Therefore, it is not technologically feasible and not practicable to manufacture, install, and service evacuated-panel technology for gas-fired, electric, and oil-fired storage water heaters on the scale necessary to serve the relevant market at the time of the effective date of the standard.

4.2.1.6 Thermophotovoltaic and Thermoelectric Generators (Gas, Oil Storage, and Instantaneous)

Both thermophotovoltaic and thermoelectric generators convert a portion of the energy produced by a gas- or oil-fired water heater burner into electricity to supply auxiliary components. This avoids the requirement of a conventional auxiliary power supply. Industry has conducted research on developing thermophotovoltaic and thermoelectric technologies to supply electricity to water heaters. For example, thermoelectric generators are used for pilot light safety valves. However, this technology option has not been developed to supply auxiliary power for larger applications, such as fans or electromechanical dampers, for use with water heater products. Currently, it is not practical to manufacture, install, or service thermophotovoltaic and thermoelectric generator technology for water heaters on a scale necessary to serve the relevant market. Therefore, these technology options are not considered technologically feasible.

4.2.1.7 U-Tube Flue (Gas and Oil Storage)

The standard length of a flue in a gas or oil-fired water heater is doubled by incorporating an inverted U-shaped flue into the water heater. A U-tube flue increases the heat transfer by increasing the heat transfer surface area. Additionally, a U-tube reduces standby losses because the shape resists heat convection, similar to a flue damper.

U-tube flue technology is not incorporated into any commercially available gas or oil-fired water heaters. Prototypes have been developed and research is currently underway. However, this technology has not been successfully demonstrated in the market, and the energy efficiency benefits can not be determined due to the lack of available products. Therefore, it is not practical to manufacture U-tube flue technology to serve the relevant market at the time of the effective date of this standard.

4.2.1.8 Reduced Burner Size (Slow Recovery) (Gas, Oil Storage, and Instantaneous)

Decreasing the burner size to increase the ratio of heat transfer area to energy input can increase the recovery efficiency of gas and oil-fired and instantaneous water heaters. However, the decreased input decreases the recovery rate, which in turn, would most likely reduce the first-hour rating. (First-hour rating directly relates to the amount of hot water the water heater can supply to the consumer.) This derating of the water heater adversely affects the utility to consumers. Additionally, first-hour rating is directly related to burner size: as burner size decreases, the amount of hot water available to the consumer also decreases. Therefore, DOE will not consider this technology option.

4.2.1.9 Two-Phase Thermosiphon (Gas and Oil Storage)

A two-phase thermosiphon (TPTS) removes the flue from the center of a gas or oil-fired storage water heater and places a heat exchanger outside of the storage tank reducing standby losses. This is similar to the side-arm heater technology option.

Manufacturers have developed working prototype water heaters using TPTS. Several units are commercially available for solar water heating applications, but not for gas or oil-fired storage water heating. TPTSs used for solar applications rely on large designs with large surface areas to maximize sun exposure. Large TPTSs are not practical for indoor installations using gas or oil. Also, incorporating the TPTS system would cause a drastic redesign of all gas and oil-fired storage water heaters with little increase in energy efficiency. The redesign would involve removing the center flue and relocating it outside the tank. As a result, only the standby losses would decrease with no affect on steady-state efficiency.

TPTS for gas and oil-fired water heaters is currently being researched. Therefore, it is not practicable to manufacture, install, and service this technology on the scale necessary to serve the relevant market at the time of the effective date of the standard.

4.2.1.10 CO_2 Heat Pump Water Heater (Electric Storage)

CO_2 heat pump water heaters use carbon dioxide as a natural refrigerant to transfer heat from the surrounding air to the water stored in the tank through a heat pump loop. Current products and prototypes can achieve coefficients of performance as high as 3.0,[2] which correspond to EFs ranging from approximately 1.0 to 3.0. This range accounts for differences in ambient air conditions, storage tank efficiency, and efficiencies of the components that make up the heat pump loop. Additionally, products are capable of functioning in cold weather climates without freezing pipes or frosting evaporators on outdoor installations. Products are predominantly available outside of U.S. markets where they have been made available by government subsidy rebate programs.[3] The necessary infrastructure to support manufacturing, installation, and service of a CO_2 heat pump water heater is not available in the United States on the scale necessary to serve the relevant market at the time of the effective date of the standard. Therefore, DOE no longer considers CO_2 heat pump water heaters for the engineering analysis.

4.2.2 Direct Heating Equipment

The following technology options are screened out for residential direct heating equipment: increased heat transfer coefficient, power burner, condensing pulse combustion, and improved fan or blower motor efficiency.

4.2.2.1 Increased Heat Transfer Coefficient (Fan Wall, Gravity Wall, Floor, Room, Hearth)

An alternative to increasing the size of the heat exchanger is enhancing the inside and outside heat transfer coefficients of the heat exchanger. Incorporating dimples or some other surface feature to enhance turbulence can increase the heat transfer coefficient when correctly designed. Also, the heat exchanger may be constructed of a material with a higher thermal conductivity than the standard cold rolled steel that is typically used.

Increasing the heat transfer coefficient for direct heating equipment is still in the research stages and prototypes have been developed. However, this technology has not been demonstrated in the relevant market, and the energy efficiency benefits cannot be determined due to a lack of available products. Currently, it would not be practical to manufacture this technology to serve the relevant market at the time of the effective date of this standard. DOE does not consider increased heat transfer coefficient any further as a technology for direct heating equipment.

4.2.2.2 Power Burner (Fan Wall, Gravity Wall, Floor, Room, Hearth)

Fan-assisted combustion can be accomplished by power burner systems positioned upstream of the combustion zone. Power burners use blowers upstream of the combustion zone to supply a more efficient fuel-air mixture to the burner. Power burners also reduce off-cycle losses by restricting air flow and convection of warm air to the vent system, similar to a vent or combustion box damper.

Power burners are typically associated with larger scale applications including commercial furnaces, boilers, and oil-fired water heaters. Additionally, power burners are typically used for high input devices that operate over 100,000 Btu/h, although units operating below this level do exist. The direct heating equipment identified in this rulemaking operates below this rating, on average. The product classes identified for this rule range from 10,000 Btu/h and less to 46,000 Btu/h and higher, and the majority of products fall between these ranges. The average product has an input rating of approximately 39,000 Btu/h. Space near the combustion chamber must be allocated for the power burner as well. DOE surveyed manufacturing literature, which suggests that approximately 1 cubic foot of space is required for power burners with inputs from 30,000 to 200,000 Btu/h. Assuming no space is available for a power burner, 1 cubic foot would be approximately more than a 10-percent increase in volume for the average heater covered by this rule.

Power burners are still being researched, and development for small applications such as gas-fired direct heating equipment is still underway. It is not practical to manufacture this technology to serve the relevant market at the time of the effective date of this standard. DOE will not consider power burners any further in the engineering analysis.

4.2.2.3 Condensing Pulse Combustion (Fan Wall, Gravity Wall, Floor, Room, Hearth)

Pulse combustion burners operate on self-sustaining resonating pressure waves that alternately rarefy the combustion chamber. Pulse combustion systems are capable of self-venting, and can draw outside air for combustion even when installed inside. Pulse combustion technologies can achieve high steady-state efficiencies and condensing operation without fans or blowers.

Similar to the condensing pulse combustion technology option considered for residential water heaters, this pulse combustion technology is not prevalent among commercially available DHE products. Therefore, the pulse combustion technology option will not be considered as a means to condense flue gases in direct heating equipment because it is not technologically feasible for DHE applications.

4.2.2.4 Improve Fan or Blower Motor Efficiency (Fan Wall, Hearth)

Fan or blower motor efficiency can be increased to reduce the electrical energy consumption of the DHE by using a brushless direct current (DC) motor, which eliminates the friction caused by the brushes of a permanent split capacitor (PSC) motor.

Assuming a fan or blower motor installed in DHE is a 1/20 horsepower motor (approximately 127 Btu/h) and is operating as low as 50-percent efficiency, the resulting energy consumption of the motor is small. Assuming a heater operates at an input of approximately 45,000 Btu/h or greater, the motor accounts for less than one percent of the total power consumption of the direct heating equipment. Motor efficiency could improve by approximately 20 percent when switching from PSC to brushless motors; however, the overall improvement to the DHE is less than one percent.

Manufacturers of DHE use high-efficiency PSC motors due to their modest cost, high efficiency, compact design, and durability. Achieving more efficient PSC motor designs for DHE applications is an ongoing challenge and no substantial gain in energy efficiency has occurred in recent years. Efficiency could be improved by increasing rotor surface area, which would increase overall motor size. However, energy efficiency improvements are difficult to achieve because of size constraints within DHE and because the affect on energy efficiency would be low. Brushless DC motors may increase energy efficiency, but this technology has not yet penetrated the market due to cost constraints. Therefore, it is not practical to manufacture, install, and service this technology for fan wall DHE on the scale necessary to serve the relevant market at the time of the effective date of the standard.

4.2.3 Pool Heaters

The following technology option is screened out for pool heaters: condensing pulse combustion.

4.2.3.1 Condensing Pulse Combustion

Pulse combustion burners operate on self-sustaining resonating pressure waves that alternately rarefy the combustion chamber and draw outside air without fans or blowers. Additionally, pulse combustion technologies can achieve high steady-state efficiencies and condensing operation without fans or blowers. High-efficiency gas-fired boilers using pulse combustion are currently available. However, pulse combustion pool heaters are not known to exist, and DOE did not identify any prototypes or research efforts. Therefore, DOE is not considering this technology option further because it is not technologically feasible at this time, and it is not practical to manufacture, install, and service on the scale necessary to serve the relevant market at the time of the effective date of this standard.

4.3 REMAINING TECHNOLOGIES

After eliminating those technologies that have no effect or do not increase energy efficiency and screening out those technologies that that do not meet the requirements prescribed at 10 CFR part 430, subpart C, appendix A, 4(a)(4) and 5(b), DOE is considering the technologies in the following list.

- Water Heaters
  - Insulation improvements
    - Increased jacket insulation (gas, electric, oil storage)
    - Insulated tank bottom (electric storage)
    - Plastic tank (electric storage)
    - Foam insulation (gas, electric, oil storage)
  - Heat Exchanger Improvements
    - Increased heat exchanger surface area (gas, electric, oil storage, instantaneous)
    - Enhanced flue baffle (gas, oil storage)
    - Submerged combustion (gas, oil storage)
    - Multiple flues (gas, oil storage)
    - Direct vent (instantaneous)
  - Alternative flue geometry (helical) (gas, oil storage)
  - Heat traps (oil storage)
  - Power vent (gas, oil storage, instantaneous)
  - Flue damper (electromechanical) (gas, oil storage)
  - Electronic (or interrupted) ignition (gas, oil storage, instantaneous)
  - Integral heat pump water heater (electric storage)
  - Condensing (gas, oil storage, instantaneous)

- Direct Heating Equipment
  - Heat exchanger improvements
    - Increased heat exchanger surface area (fan wall, gravity wall, floor, room, hearth)
    - Multiple flues (fan wall, gravity wall, floor, room, hearth)
    - Multiple turns in flue (fan wall, gravity wall, floor, room, hearth)
    - Direct vent (concentric venting) (fan wall, gravity wall, floor, room, hearth)
  - Electronic ignition (fan wall, gravity wall, floor, room, hearth)
  - Thermal vent damper (fan wall, gravity wall, floor, room, hearth)
  - Electrical vent damper (fan wall, gravity wall, floor, room, hearth)
  - Induced draft (fan wall, gravity wall, floor, room, hearth)
  - Increased insulation (floor)
  - Condensing (fan wall, gravity wall, floor, room, hearth)
  - Two-stage and modulating operation (fan wall, gravity wall, floor, room, hearth)
  - Air circulation fans (floor, room, hearth)
  - Sealed combustion (fan wall, gravity wall, floor, room, hearth)

- Pool Heaters
  - Electronic Ignition
  - Improved heat exchanger design
  - More effective insulation (combustion chamber)
  - Power venting
  - Sealed combustion
  - Condensing

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