ENERGY STAR Market & Industry Scoping Report
Residential Clothes Dryers
November 2011

U.S. Environmental Protection Agency (EPA) consistently looks for new opportunities to expand ENERGY STAR to new product categories that will deliver significant benefits to consumers and the environment in the form of energy and dollar savings plus greenhouse gas reductions. A key step in this evaluation is the development of a scoping report that provides a snapshot of the product market, energy use, and savings potential associated with an ENERGY STAR program for the scoped product type. EPA uses scoping findings to prioritize product specification development work. While scoping reports are drafted primarily for internal evaluation purposes, and are not intended to be exhaustive but rather a guidepost for the ENERGY STAR program, EPA makes the reports available with the interest of benefiting other efficiency programs evaluating similar opportunities. For more information about the ENERGY STAR specification development process, go to: www.energystar.gov/productdevelopment.

1. *Product & Technology Overview*

For the purposes of this report, a clothes dryer is defined as a cabinet-like appliance designed to dry fabrics in a tumble-type drum with forced air circulation, with blower(s) driven by an electric motor(s) and either gas or electricity as the heat source. The U.S. Department of Energy (DOE) latest appliance standards classify clothes dryers into a number of different product classes (Table 1), based on whether or not the product is vented, the energy source (gas or electric), input voltage, and the dryer's capacity in cubic feet (ft^3).

Table 1: Clothes Dryer Product Classes

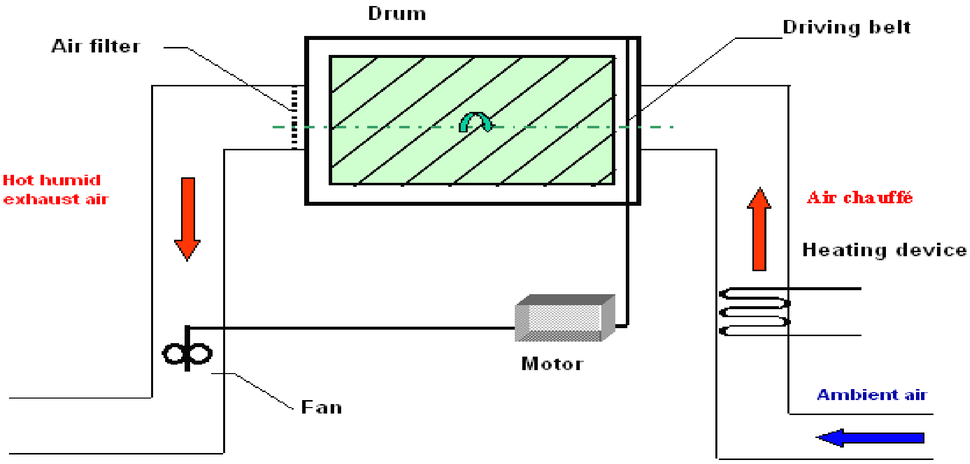
U.S. DOE Product Classes (as shown in 10 CFR 430.32(h))*	
Vented	Electric, Standard (4.4 ft^3 or greater capacity)
	Electric, Compact (120V) (less than 4.4 ft^3 capacity)
	Electric, Compact (240V) (less than 4.4 ft^3 capacity)
	Gas
Ventless	Electric, Compact (240V) (less than 4.4 ft^3 capacity)
	Electric, Combination Washer-Dryer

* Note, these product classes correspond to the energy conservation standards for which manufacturers must comply beginning January 1, 2015.

Vented and Ventless Dryers

In vented dryers, ambient air comes in from the surrounding environment via opening in the metal structure. Ambient air is heated with a heating element and blown into the drum, where the drying process occurs. Once the warm air is saturated with the laundry moisture, it is evacuated outside through a flexible pipe. The drum is set into rotation by the motor in order to spread the load in the whole available volume.

Figure 1: Electric Vented Clothes Dryer[1]



Instead of exhausting the air, ventless dryers typically use a heat exchanger to cool the air and condense the water vapor into either a drainpipe or collection tank. Although not as common in the U.S., two types of condenser dryers can be found of the market: air and water condenser dryers. The difference lies in the heat exchange process; the internal warm air is cooled either using ambient air or cold water. Water condensation is most common for combination all-in-one washer-dryers whereas the majority of condensing dryers use air condensation.

Ventless dryers offer the versatility of not needing to be vented to the outside (useful in spaces such as apartments and condominiums). Waste heat goes to the surrounding environment rather than being vented outside. If the dryer is installed in a home's conditioned space, this can be a benefit on cold days but a drawback on hot days.

Energy Source: Gas and Electricity

Clothes dryers are powered by either utility supplied electricity or gas (natural gas or propane). Electric dryers require a dedicated 240 or 120 volt (V) outlet while gas dryers, which tend to have lower operating costs, require a dedicated gas hook-up. Due to safety risks associated with the combustion of gas, gas dryers are always vented, while electric dryers can be vented or ventless.

Product Components

The basic components of a conventional clothes dryer are described in Table 2.

[1] PricewaterhouseCoopers. *Ecodesign of Laundry Dryers. Preparatory Studies for Ecodesign Requirements of Energy-using Products (EuP) – Lot 16.* Final Report March 2009.

Table 2: Clothes Dryer Main Product Components

Component	Description
Drum	Heated air evaporates water from the clothes in the drum, which typically rotates around 40 revolutions per minute (RPM). Evaporating water cools the air to 90 - 170°F and increases its humidity as it leaves the drum.
Motor	Motor rotates the drum and drives the fan to move the air. Typically draws 200 - 300 watts (W) of electricity. Most dryers use a single-phase capacitor-run induction motor. Inverter-fed three-phase permanent magnet synchronous motors can be used, but their use is cost-dependant. Motor options include brushless direct current (DC) motor, brushless direct drive, and three phase motors and their associated controls. Some clothes dryers use separate motors to rotate the drum and to drive the fan.
Fan	The fan draws the air through the other components at 100 - 150 cubic feet per minute (CFM).
Electric Heater	Electric resistance heaters typically draw about 5,000 - 5,500 watts (230 volts and 22 amps). The air from the cabinet is drawn into the heater duct and heated to 200°F to 300°F. The main technologies are sheathed element heaters and open coil heating elements.
Gas Burner	Gas burners are typically rated at 20,000 - 25,000 British thermal units/hour (Btu/hour), which equals 6 - 7 kilowatts/hour (kWh). Most standard gas dryers today use inshot style burners to deliver heat to the drum.

2. *Market Assessment and Usage Assumptions*

U.S. Market and Usage Patterns

Existing Stock of Clothes Dryers

Household penetration of clothes dryers has increased by nearly 6% over the last decade.[2] As of 2009, almost 80% of U.S. households have a clothes dryer. Approximately 80% of the installed base of clothes dryers in U.S. households are electric, while the remaining are gas dryers. The mix of electric dryers and gas dryers has remained relatively stable, with electric dryers experiencing just over 2% increase in household penetration over the last decade.[3] The vast majority of dryers in the U.S. require an exhaust vent, as ventless dryers represent less than 1% of the market.[4]

Table 3: Household Penetration of Clothes Dryers by Energy Source[5]

Clothes Dryer	U.S. Households (millions)	Percentage of Total Households
Use a Clothes Dryer At Home	**90.2**	**79%**
Electric	*71.8*	*80%*
Natural Gas	*17.5*	*19%*
Propane/LPG	*1.0*	*1%*
Do Not Use a Clothes Dryer At Home	**23.4**	**21%**

[2] DOE– EIA. Residential Energy Consumption Survey 2001, 2005, 2009 Public Use Data Files.
[3] Ibid.
[4] Meyers, S., Franco, V., Lekov, A., Thompson, L., and A. Sturgen. *Do Heat Pump Clothes Dryers Make Sense for the U.S. Market?* Presented at the 2010 ACEEE Summer Study of Energy Efficiency in Buildings. August 2010.
[5] DOE– EIA. Residential Energy Consumption Survey 2009 Public Use Data Files.

U.S. Retail Sales of Clothes Dryers

In 2010, 6.5 million clothes dryers were sold in the U.S.,[6] 80% of which were electric dryers. Similar to other durable goods, sales of clothes dryers have decreased over the past few years, largely due to the economic downturn.

Clothes Dryer Lifetime

The average lifetime of clothes dryers is generally estimated in the range of 12[7]-16[8] years. Table 4 provides the most recent data for the age distribution of clothes dryers. *This report assumes an average lifetime of 16 years.*

Table 4: Age Distribution of Clothes Dryers[9]

Age of Clothes Dryer	U.S. Households (millions)	Percentage of Total Households
Less than 2 Years	11.9	13%
2 to 4 Years	21.4	24%
5 to 9 Years	30.1	33%
10 to 14 Years	16.2	18%
15 to 19 Years	6.2	7%
20 Years or More	4.5	5%

Consumer Usage Behavior

The current DOE test procedure for measuring the energy consumption of clothes dryers assumes 416 cycles per year. In the amended test procedure for clothes dryers that DOE published in January 2011, the number of cycles was revised to 283 cycles per year, based on data from the 2005 Energy Information Agency (EIA) Residential Energy Consumption Survey (RECS).[10] Within homes that have a clothes dryer, about 82% use the clothes dryer every time clothes are washed.

Table 5: Clothes Dryer Frequency of Use (2009)[11]

Clothes Dryer Use	U.S. Housing Units (millions)
Used Every Time Clothes are Washed	74.4
Used For Some, But Not All Loads	13.8
Used Infrequently	2.1
Do Not Use a Clothes Dryer At Home	23.4

[6] Appliance Magazine. *2010 U.S. Appliance Shipment Statistics*. April 2010.
[7] Appliance Magazine and Association of Home Appliance Manufacturers
[8] U.S. Government, Federal Register / Vol. 76, No. 4 / Thursday, January 6, 2011 / Rules and Regulations page 972-1036
[9] DOE– EIA. Residential Energy Consumption Survey 2009. Public Use Data Files.
[10] Appendix D to Subpart B of Part 430 – Uniform Test Method for Measuring the Energy Consumption of Dryers
[11] DOE– EIA. Residential Energy Consumption Survey 2009. Public Use Data Files.

Pricing

Generally, gas dryers cost around $50 more than comparable electric dryers, although savings in fuel costs typically make up the difference in the long run.[12] Additionally, some gas utilities offer consumers rebates (usually, in the range of $50-100) for installing gas dryers. Condensing dryers are available in the U.S. from at least five manufacturers (GE, LG, Bosch, ASKO, and Miele). These units typically cost $950-$2,050 and are available in small to medium capacities.[13]

U.S. Consumer Preferences

TIAX, a technology processing and commercialization company, conducted a consumer survey prior to the development of its heat pump clothes dryer prototype for Whirlpool Corporation, in an effort to identify the attributes most important to consumers. The top three purchase criteria for clothes dryers were listed as reliability, features and functions, and price.[14] The survey found that consumers were willing to pay significantly more for energy savings, though cost sensitivity varied by location, and consumers were skeptical of claims of significant energy savings. Consumer interest in clothes dryer energy efficiency was also found to be more closely coupled to a desire to be environmentally sound, than to the payback.

International Markets and Usage Patterns

It is worth noting the differences of among various domestic markets for clothes dryers. For instance, condenser dryers and compact sizes have a far higher prevalence in Europe than in the U.S., and the market penetration of electric dryers is even greater in Europe. As a result, European consumers are more accustomed to longer drying times and ventless models.[15] Canada and Australia are more similar to the U.S. in household characteristics and in the penetration of natural gas dryers. Additionally, almost all dryers in Canada are vented models.[16]

3. *Clothes Dryer Test Procedures and Standards*

U.S. Department of Energy Test Procedure

(as shown in Appendix D and Appendix D1 of 10 CFR Part 430, Subpart B)

Clothes dryer energy consumption in the U.S. is measured in accordance with the DOE test procedure. DOE published an amended clothes dryer test procedure on January 6, 2011.[17] Manufacturers will be required to use this amended test procedure to determine compliance with the new clothes dryer energy efficiency standards starting in 2015. Main changes to the amended DOE test procedure include:

1. Incorporates measures of standby and off mode consumption

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[12] Consumer Energy Center. Clothes Dryers – Buying Smart. 2011. Available online at: www.consumerenergycenter.org/home/appliances/dryers.html

[13] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.

[14] Pescatore, P., and P. Carbone. *High Efficiency High Performance Clothes Dryer: Final Report to Department of Energy*. TIAX. March 2005.

[15] PricewaterhouseCoopers. *Ecodesign of Laundry Dryers. Preparatory Studies for Ecodesign Requirements of Energy-using Products (EuP) – Lot 16.* Final Report March 2009.

[16] Nipkow, J., Josephy, B., Bush, E., Werle, R., and C. Granda. *Energy-efficient heat pump dryers – European experiences and efforts in the U.S. and Canada*. May 2011.

[17] U.S. Government, Federal Register / Vol. 76, No. 4 / Thursday, January 6, 2011 / Rules and Regulations page 972-1036

2. Includes ventless clothes dryers[18]
3. Clarifies test conditions for gas dryers and dryer drum capacity measurements
4. Updates detergent specifications for dryer test cloth preconditioning
5. Adopts technical changes to better reflect current usage patterns and capabilities of clothes washers and dryers

Both existing and amended DOE test procedures normalize the per-cycle energy consumption equation to represent the energy consumption required to dry the test load to between 2.5 and 5 percent remaining moisture content (RMC) at a single setting (highest heat). Both test procedures multiply the per-cycle energy consumption by fixed field-use factors to account for energy consumption due to over-drying by time termination dryers (field use factor = 1.18), and automatic termination dryers (field use factor = 1.04). This does not test the effectiveness of the clothes dryer's auto termination. However, testing by both Ecos Consulting for the National Resources Defense Council (NRDC)[19] and *Consumer Reports* has found wide variation in how effectively moisture sensors operate. In August 2011, DOE released a Request for Information (RFI) to further investigate the effects of automatic termination.

U.S. Federal Energy Conservation Standards

The current energy efficiency performance metric for clothes dryers is Energy Factor (EF), which measures the pounds of clothing (saturated to a certain standardized extent) that can be dried per electric kilowatt-hour (kWh) of electricity (for gas dryers, per "equivalent" kWh of natural gas consumed). The DOE's new energy efficiency performance metric, Combined Energy Factor (CEF), integrates energy use in the standby mode and off mode with the energy use of drying. DOE recently amended the federal energy conservation standards for clothes dryers. Manufacturers will be required to demonstrate compliance with these new standards beginning January 1, 2015. Tables 6 and 7 summarize existing and amended standards, assumption on number of cycles per year for dryer categories, and annual energy use.

Table 6: Existing Federal Standards (as shown in 10 CFR Part 430.32(h))

	Existing Federal Standard Calculated with Existing Test Procedure	
Product Class	EF (lb/kWh)	Average Annual Energy Use in kWh (416 cycles/yr)
Electric, Standard (4.4 ft^3 or greater capacity)	3.01	967
Electric, Compact (120V) (less than 4.4 ft^3 capacity)	3.13	399
Electric, Compact (240V) (less than 4.4 ft^3 capacity)	2.90	430
Gas	2.67	1091

[18] The existing test procedure for clothes dryers requires the use of an exhaust restrictor to simulate the backpressure effects of a vent tube. The amended test procedure altered this requirement so that it only applied to vented clothes dryers and included separate procedures and product class definitions for "ventless" clothes dryers.
[19] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.

Table 7: Amended Federal Standards (as shown in 10 CFR Part 430.32(h))

	Amended Federal Standard Calculated with Amended Test Procedure	
Product Class	CEF (lbs/kWh)	Average Annual Energy Use in kWh (283 cycles/year)[20]
Vented Electric, Standard (4.4 ft^3 or greater capacity)	3.73	684
Vented Electric, Compact (120V) (less than 4.4 ft^3 capacity)	3.61	305
Vented Electric, Compact (240V) (less than 4.4 ft^3 capacity)	3.27	340
Vented Gas	3.30	748
Ventless Electric, Compact (240V) (less than 4.4 ft^3 capacity)	2.55	372
Ventless Electric, Combination Washer-Dryer	2.08	463

4. *Energy Efficiency Assessment*

Conventional dryers are about 50-70% efficient at removing water.[21,22] Using heat recovery, heat pumps, or the desiccating potential of dry air can theoretically present efficiencies of over 100%.[23] Residential clothes dryers account for approximately 6% of residential electricity use.[24] Traditionally, it's been assumed that the energy efficiency of clothes dryers does not vary appreciably. Publically available data on clothes dryer supports this, suggesting all models have similar energy use. This view has begun to change in the last few years as a result of new research that is suggesting different methods of testing may reveal greater differences in efficiency and through the development of new and improved technologies for improving dryer efficiency.

Clothes dryer testing conducted by Ecova (formerly Ecos Consulting) for NRDC has suggested that when tested under conditions different than current DOE test (which does not assess the effectiveness of automatic termination or multiple cycle settings), conventional dryers can vary by about 20 to 30% in the amount of energy required to dry the same load of clothes.[25]

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[20] U.S. Department of Energy - Technical Support Document for Residential Dryers, EERE-2007-BT-STD-0010.
[21] Converting water from a liquid state to a vapor state requires about 500 kcal of heat per kg of water (0.308 kWh per pound). Multiplying by 0.308 kWh per pound of water removed from the load, and dividing by the energy consumption associated with each cycle provides an estimate of overall dryer efficiency.
[22] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.
[23] Ibid.
[24] Bendt, P. *Are We Missing Energy Savings in Clothes Dryers?* Presented at the 2010 ACEEE Summer Study of Energy Efficiency in Buildings. August 2010.
[25] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council..

Savings Opportunities

The most energy efficient way to reduce clothes dryer energy use is to spin more moisture from the load after it washed and before it enters the clothes dryer. Today, clothes washers with a horizontal axis configuration and high spin speeds of more than 1,000 revolutions-per-minute (RPM) are common.

The following section discusses a variety of technology design options to increase the energy efficiency of clothes dryers, broken into different categories. For each category, a table is provided summarizing available technology options largely drawn from recent DOE research and analysis,[26] a short description of these options, and estimated savings for these options. Estimated savings are based on initial review of research reports and discussions with manufacturers, and DOE's review of various trade publications, research reports, discussions with manufacturers, and product literature. Some of these options are then further discussed, along with some of the additional considerations for improving the energy efficiency and reducing the environmental impact of clothes dryers.

Dryer Control or Drum Upgrades

Table 8: Energy Efficient Technology Options – Dryer Control or Drum Upgrades

Technology Option	Description	Estimated Savings
Improved Termination	Automatic termination by temperature, moisture sensing, end-of-cycle detection	10% for temp., 15% for moisture
Increased Insulation	Insulating the dryer drum reduces heat loss	Up to 6%
Modified Operating Conditions	Reducing air flow and/or heat input rate	5-8%
Improved Air Circulation	Better drum design or dryer booster fans to improve airflow	1-2% for better drum design, N/A for dryer booster fans
Reverse Tumble	Reverse rotational direction early to increase the separation of clothing and dry more evenly and quickly	N/A
Improved Drum Design	Improving the drum design, including internal vane design, which can promote clothes separation during tumbling	N/A

Instead of only having a timer that terminates the dry cycle after a certain time interval selected by the consumer, many new clothes dryers offer an automatic termination setting. However, this feature may be over-ridden by consumers who continue to operate dryers on a timed basis as they have in the past.

Auto termination controls the length of the drying cycle, using temperature sensors and/or moisture sensors to terminate the cycle when the clothes are dry. Automatic termination can be accomplished using a temperature sensor that detects the temperature of exhaust air. Manufacturers have indicated to DOE that moisture sensing (that assess conductivity) can increase accuracy of auto termination relative to only using a temperature sensor.[27] Several

[26] U.S. Department of Energy - Technical Support Document for Residential Dryers, EERE-2007-BT-STD-0010.
[27] Ibid.

sources have claimed that temperature sensors provide 10% real-world energy savings, whereas moisture sensors yield a 15% savings.[28]

Research has also suggested the accuracy of moisture sensors and controls varies among clothes dryers currently available on the U.S. market.[29] According to one source, the location of the moisture sensor has the potential to increase accuracy and save energy. Placing moisture sensors in the "fins" located around the drum perimeter instead of the in a fixed location on the front inside of the dryer cabinet can lead to more clothes coming in contact with sensors and better detection of proper cycle termination.[30]

Research by Ecos Consulting for NRDC has estimated that the difference between a standard clothes dryer and one that is effective at turning itself off when clothes are actually dry is about 0.76 kWh per load (5,000 kWh over typical lifetime).[31] Auto termination can be improved by increasing the accuracy of resistance sensors near the end of the dry cycle when RMC is low, and by improving the accuracy of end-of-cycle detection through new dryer process modeling.

Dryer process modeling and algorithms can improve drying performance and energy efficiency. Intelligent load control systems are capable of adapting the drying process to the load inside the dryer, thus optimizing the performance, which has advantages for partial loads. The Ecodesign study indicates that an intelligent load sensor could increase efficiency about 4-5%.[32]

Some clothes dryers also incorporate air flow sensors to alert user of lint filter clogging, duct clogging, and improper installation of the duct. A manufacturer indicated that reduced air-flow may reduce overall energy efficiency by over 30% and could be a fire hazard. However, Consumer Reports' product testing suggested the performance of these sensors is inconsistent.[33]

Ecodesign estimates that improved insulation could have energy savings of about 4% for air condensed dryers and 3% for vented dryers. DOE cites that consumer simulations by researchers have shown a 6% energy savings, although most manufacturers have suggested there is little efficiency gain from insulation.[34]

Heat Recovery

Table 9: Energy Efficient Technology Options – Methods of Heat Recovery

Technology Option	Description	Estimated Savings
Recycle Exhaust Heat	Portion of the exhaust air stream is reintroduced at the dryer air inlet, thus reducing the energy needed to raise inlet air temperatures	3-6% in NIST testing
Inlet Air Preheat	Heat exchanger used to recover exhaust heat energy and to preheat inlet air	2-6%

[28] Ibid.
[29] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.[30] Ecos Consulting. 4 Aug. 2011. E-mail correspondence.[31] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.
[30] Ecos Consulting. 4 Aug. 2011. E-mail correspondence.[31] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.
[31] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.
[32] PricewaterhouseCoopers. *Ecodesign of Laundry Dryers. Preparatory Studies for Ecodesign Requirements of Energy-using Products (EuP) – Lot 16.* Final Report March 2009.
[33] Consumers Union. "Dryer Danger" http://www.consumerreports.org/cro/video-hub/appliances/laundry--cleaning/dryer-danger/16601904001/102824143001/ Accessed August 2011.
[34] U.S. Department of Energy - Technical Support Document for Residential Dryers, EERE-2007-BT-STD-0010.

Technology Option	Description	Estimated Savings
Inlet Air Preheat, Condensing Mode	Use condenser to capture some of the heat in the exhaust air stream	Up to 7% in closed cycle, and up to 14% in open cycle

About 20-25% of the total heat input energy for a dryer is lost through the dryer vent.[35] It is possible to recycle exhaust heat, by reintroducing into the dryer air inlet, some of the hot, dry exhaust air available late in the drying cycle when most of the moisture has already been evaporated. A mesh filter can be used to minimize re-circulated lint. It is also possible to use a heat exchanger to recover heat from the exhausted air and pre-heat inlet air. Heat exchangers have the advantage of being able to be used with gas dryers because none of the exhaust air re-enters the drum. According to the Ecodesign study, the recovery could lead to 8% energy savings.[36] DOE estimates savings of up to 6%.[37]

Inlet air can also be pre-heated with a condenser that captures some of the sensible and latent heat available in the exhaust air stream. The water vapor in the exhaust air condenses out and therefore more heat energy can be transferred than in a sensible heat exchanger system. Research has shown that compared to a conventional air vented dryer, an open-cycle condensing dryer is about 14% more efficient and a closed-cycle condensing dryer is 7% more efficient.[38] However, manufacturers have indicated that only minimal (1-3%) efficiency can be attained with inlet air preheat.[39] One manufacturer has also indicated a condensation dryer is most efficient when loaded at or near full capacity, a condition not reflected in the DOE test procedure. Although there are a number of condenser dryer models available in the U.S. (where they are used to avoid the need for venting), these condenser dryers are not using heat recovery, but instead use a heat exchanger to dissipate waste heat from the dryer.

An alternative approach is to compress the exhaust air in order to extract water vapor and transfer the latent heat to the remaining gaseous stream. After water is drained from this compressor, the pressurized air is allowed to expand and be superheated before re-entering the drum. Some research has suggested this can be as efficient as heat pump dryer, while having a shorter drying time.[40]

Heat Generation Options

Table 10: Energy Efficient Technology Options – Heat Generation Options

Technology Option	Description	Estimated Savings
Heat Pump, Electric Only	Recirculating exhaust air back to the dryer while moisture is removed by a refrigeration-dehumidification system	20-60%
Microwave, Electric Only	Water absorbs microwave energy, and heating the water enough to cause evaporation	Up to 26%
Modulating Heat	Matching the heat input rate to the load's moisture level	Up to 25%
Water-Cooling, Ventless Electric Only	Internal water-cooled condenser heat exchanger system condenses the water vapor in the air exiting the drum	N/A

[35] Ibid.
[36] PricewaterhouseCoopers. *Ecodesign of Laundry Dryers. Preparatory Studies for Ecodesign Requirements of Energy-using Products (EuP) – Lot 16.* Final Report March 2009.
[37] U.S. Department of Energy - Technical Support Document for Residential Dryers, EERE-2007-BT-STD-0010.
[38] Ibid.
[39] Ibid.
[40] Ibid.

Technology Option	Description	Estimated Savings
Indirect Heating	Heat energy derived from home's heating system	Up to 50% (estimated by one technology manufacturer)

A heat pump dryer works by having a heat pump that extracts heat from the ambient air and releases that heat at a higher temperature inside the drum. A typical heat pump uses 1 kWh of electricity to move 2 kWh of heat.[41] The air in a ventless heat pump dryer moves in a closed loop, where air is recycled and heated again. It is possible to create an open system where a portion of the exhaust air is vented outside. Energy savings estimates from heat pump technology range from 20-60%. Based on several manufacturer estimates, the potential payback period could be within the average estimated lifetime of the model. However, a paper presented at the 2010 ACEEE Summer Study on Energy Efficiency in Buildings indicated that based upon the current price differential for a heat pump model (estimated to be about $400), there is only positive economic benefit for households with high clothes dryer usage (> 700 cycles/yr). For regions of the country with high electricity rates, they found there was a positive economic benefit for households with moderately high clothes dryer usage (>500 cycles/yr).[42] As of November 2011, there are no heat pump dryers available in the U.S., although they are readily available in Europe and Australia from a number of different manufacturers. Those models typically have a drying time of about twice as long as a typical U.S. dryer; prototypes have been developed for the U.S. market that keep drying times closer to typical U.S. models by using higher temperatures and airflows.[43]

Conventional gas dryers use a single burner at a fixed input rate and turn off and on as needed, depending on the cycle chosen, and the temperature of the exhaust air. Modulating the heat source can avoid overheating clothes and thereby save energy, particularly as the load approaches dry. The aim is to match the heat input rate to the load's moisture level, as this technology can respond subtly to changes in dryer temperature and humidity levels.[44] This can be accomplished with a modulating gas valve and additional controls.

TIAX developed a modulating gas dryer prototype that achieved up to 25% energy savings and 20-40% time-savings relative to a conventional natural gas dryer for small- and medium-size loads.[45] A second prototype developed by Cameo, a General Electric subsidiary, confirmed shorter drying times but did not achieve equivalent energy savings.[46] Modulating technologies may provide consumers interested in lower dry times a viable option for energy savings as opposed to heat pump technologies that tend to increase dry times and cost more.[47] Heat can also be modulated in an electric dryer using multi-element resistance heater or single element with modulating current.

"Eco-Mode" options or other similar settings can save energy by reducing power output while lengthening the drying process and/or stopping the dryer before clothes are completely dry. Such settings may also incorporate a variable heat source. One manufacturer has noted a 40%

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[41] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.
[42] Meyers, S., Franco, V., Lekov, A., Thompson, L., and A. Sturgen. *Do Heat Pump Clothes Dryers Make Sense for the U.S. Market?* Presented at the 2010 ACEEE Summer Study of Energy Efficiency in Buildings. August 2010.
[43] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.
[44] Pescatore, P., and P. Carbone. *High Efficiency High Performance Clothes Dryer: Final Report to Department of Energy*. TIAX. March 2005.
[45] Ibid.
[46] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.
[47] U.S. Department of Energy - Technical Support Document for Residential Dryers, EERE-2007-BT-STD-0010.

dryer energy savings from using this energy efficient mode or cycle. However, recent testing by Ecova (formally Ecos Consulting) on behalf of NRDC, found that “eco modes” on two dryer models provided no energy savings if clothes are dried to a similar level of dryness reached in other modes.[48] Ecova suggested a truly energy-saving “eco-mode” could be accomplished by modulating the heater power and fan speed.

A lower heat setting can also improve energy efficiency and reduce energy consumption, since less energy use used to heat air, cloth and metal. For example, Ecova testing for NRDC found a 13% difference in energy consumption between the highest and lowest heat settings for one clothes dryer model tested when drying the same load, at the expense of a 14-minute increase in drying time.[49]

It is possible for the necessary heat for clothes dryers to be derived indirectly, from a home hydronic heater system. The dryer would use some form of heat exchanger or radiator to utilize heat from the heater system’s hot water that is brought to the dryer through plumbing. One source claims that energy savings up to 50% and time-savings up to 41% are possible.[50]

Component Improvements

Table 11: Energy Efficient Technology Options – Component Improvements

Technology Option	Description	Estimated Savings
Improved Motor Efficiency	Improving the overall efficiency of the motor or using a split motor design to adjust air flow rates	1-5%
Improved Fan Efficiency	Increasing blower efficiency	N/A

Many dryers use a single motor to rotate the drum and move the air using a fan. According to manufacturers, potential efficiency gains can result from improving the motor design, which could increase savings by 1-5%, and through using a split motor design and decoupling the two functions of rotation and airflow, which could theoretically improve efficiency.[51] Changing the blade curves of the blower fan could also possibly lead to efficiency gains, but these gains have not been quantified.[52]

Standby Power Improvements

Table 12: Energy Efficient Technology Options – Standby Power Improvements

Technology Option	Description	Estimated Savings
Switching Power Supply	Better power supplies on the control board	N/A
Transformerless Power Supply with Auto-Powerdown	Implementing a transformerless power supply for the microprocessor logic, as well as a conventional power supply activated when the dryer is in active mode	N/A

[48] Denkenberger, D., Mau, S., Calwell, C. and Wanless, E. 2011. *Residential Clothes Dryers: A Closer Look at Energy Efficiency Test Procedures and Savings Opportunities.* Ecova prepared for Natural Resources Defense Council.
[49] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.
[50] U.S. Department of Energy - Technical Support Document for Residential Dryers, EERE-2007-BT-STD-0010.
[51] Ibid.
[52] Ibid.

Energy used to operate dryer controls in standby mode varies between 1.4 to 3.1 watts, adding about 180-400 kWh over the life of the dryer.[53] A switching power supply could provide a modest reduction in standby power use and there are a large number of dryers on the market in the U.S. that already incorporate a switching power supply.[54]

HVAC Effects

A clothes dryer releases heat to the surrounding environment. Conventional vented dryers also vent air outside the building. The associated heating, ventilation, and air conditioning (HVAC) impact of dryers depends upon a number of variables including climate and placement of a dryer (i.e., in a conditioned or unconditioned space). It is an area of ongoing research. In a recent rulemaking analysis, DOE estimated the impact of home heating/cooling loads on total clothes dryer energy use is about 6% for vented dryers and 11% for ventless dryers, while concluding that the HVAC impact is similar across different levels of dryer efficiency.[55] There could also be energy savings from using outside air intake in the summer. When coupled with heat recovery (which would allow the outside air intake to be advantageous in both summer and winter), initial estimates have suggested the savings may be as much as 2.35 kWh per load.[56]

Site v. Source Considerations

Gas dryers not only tend to have lower operating costs for consumers, but allow for significant savings of CO_2 emissions compared to electric dryers since they use primary energy, and therefore avoid the efficiency losses of electric dryers as a result of the electricity generation and distribution. In the clothes dryer test procedure, natural gas consumption is converted into an equivalent electrical consumption on a site-basis, which does not take into account these generation and distribution losses.

To more fully compare savings between electric and gas dryers, some stakeholders have suggested methods that focus on source BTUs, total CO_2 emissions, or energy cost. The standard natural gas dryer uses less source energy, costs less, and emits less carbon dioxide per pound of water removed than most other options, potentially including heat pump dryers. However, the efficiency (as measured by EF or CEF) of gas dryers is generally lower than that of standard electric dryers.[57]

5. *Energy and Cost Savings Potential*

The only two known databases of clothes dryer energy data relevant to the U.S. market are maintained by the California Energy Commission (CEC) and Natural Resources Canada (NRCan). However, the data given from these databases are of EF levels measured under the DOE test procedure currently used by manufacturers to comply with federal appliance standards. The savings analysis below considers the efficiency of dryers as measured by CEF and rated under the 2011 amended DOE test procedure.[58]

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[53] Ibid.
[54] Ibid.
[55] U.S. Government, Federal Register / Vol. 76, No. 4 / Thursday, January 6, 2011 / Rules and Regulations page 972-1036
[56] Bendt, P., Calwell, C., and L. Moorefield. 2009. *Residential Clothes Dryers: An Investigation of Energy Efficient Test Procedures and Savings Opportunities*. Ecova (formerly Ecos Consulting) prepared for Natural Resources Defense Council.
[57] Ibid.
[58] As noted in Section 4, this amended DOE test does not address the effectiveness of auto termination, though manufacturers and efficiency advocates have filed a petition requesting the further test procedure revisions to address auto termination be considered by DOE.

Initial estimates of energy and CO_2 savings were developed for two efficiency scenarios. The first scenario assumes energy savings of 10%, achieved using a collection of designs and technologies highlighted in the previous section. The second scenario assumes more aggressive energy savings of 30% for standard electric dryers and 20% for gas dryers that could be realized by achieved using more advanced technology such as heat pumps or modulation technology.

Baseline CEF levels of 3.25 (for a gas dryer) and 3.66 (for an electric dryer) were used based on an estimated shipment-weighted average of the least efficient models on the market. These levels are slightly lower than the 2015 federal minimum efficiency standards levels and assume a standby power consumption of 1.5 W. For these initial savings estimates, efficient CEF levels of 3.61 (gas) and 4.06 (electric) represent a 10% energy savings over baseline. CEF levels of 4.06 (gas) and 5.22 (electric) represent a 30% energy savings for electric dryers and 20% energy savings for gas dryers.[59]

Under the first scenario, the estimated annual household savings ranges from $3 (for gas dryers) to $7 (for electric dryers), which translates into lifetime savings of $47 to $114.[60] The second, more aggressive scenario offers annual savings that range from $6 (gas) to $21 (electric), which provides lifetime savings of $95 to $342.[61]

Assuming 25% of dryers sold in the U.S. were more efficient,[62] the first-year savings on a national scale ranges from 86,000 MWh and 76 billion Btu (first scenario) to 256,000 MWh and 152 billion Btu (second scenario). These savings translate into annual CO_2 emission reductions on the order of 141 to 412 million lbs per year (assuming a conversion of 1.54 lbs CO_2 per kWh and 117 lbs CO_2 per MBtu).

6. *Key Market Players*

Trade Associations

The Association of Home Appliance Manufacturers (AHAM) aims to enhance the value of the home appliances industry through leadership, public education, and advocacy. AHAM provides services to its members including government relations, certification programs for room air conditioners, dehumidifiers, and room air cleaners; an active communications program; and technical services and research.

Manufacturers

Common clothes dryer brands on the U.S. market include Frigidaire (Electrolux), GE, Kenmore, LG, Maytag, Samsung, and Whirlpool. Whirlpool is the largest U.S. manufacturer of clothes dryers with well over half the market share (Maytag, Whirlpool, and Kenmore brands).

Energy Efficiency Program Sponsors

A number of utilities across the nation have expressed interest in promoting efficient clothes dryers to customers through incentives.

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[59] Note: CEF levels set here are used for illustrative purposes, to demonstrate 10% and 30% improvements in energy savings. CEF level in Scenario 2 for gas is higher than the maximum technology level set by DOE in their TSD documents (3.61 CEF). CEF level in Scenario 2 for electric is lower than the maximum technology level set by DOE in their TSD documents (5.42 CEF).
[60] Assumes $0.1089/kWh (Source: 2011 U.S. Electric Rate: Energy Information Administration, Annual Energy Outlook 2011 (Early Release) edition. (converted from 2009 to 2010 dollars)), $10.50/MBTU (Source: 2011 U.S. Electric Rate: Energy Information Administration, Annual Energy Outlook 2011 (Early Release) edition (converted from 2009 to 2010 dollars)) and, and 16 year lifetime (Source: 2011 DOE Clothes Dryer Final Rule).
[61] Ibid.
[62] Unit shipments are estimated based on 2010 U.S. Appliance Shipment Statistics from *Appliance Magazine*.

7. Stakeholders and Existing Programs

International Level

European Union

Virtually all conventional electric dryers in the EU have migrated steadily upward from the F and G-rating to the C-rating since the EU adopted categorical labeling. Some units with advanced sensing capabilities have been able to achieve a B-rating; A-rated units are almost all heat-pump models. Gas dryers are excluded from the EU label.

European Eco-Design Requirements for Energy-Using Products (EuP)

Under a Directive for defining eco-design requirements of energy-using products, the European Council and European Parliament completed a preparatory study of clothes dryers in March 2009 analyzing technical, environmental, and economic aspects. A proposed draft regulation released in June 2010 set forth that the energy label shall be revised, but no Eco-design requirements shall be set for clothes dryers.

Other International Programs

Canada has a mandatory EnerGuide label for clothes dryers and minimum energy efficiency regulations. Australia also has an established Star-rating scheme for clothes dryers.

Collaborative Labeling and Appliance Standards Program (CLASP)

Established in 1999, CLASP's mission is to serve as the primary resource and voice for appliance energy efficiency worldwide. CLASP recently chose to focus on energy efficient clothes dryers, a technology with a strong potential to generate energy savings and carbon reductions.

U.S. Initiatives

Super Efficient Dryer Initiative (SEDI)

The Super Efficient Dryer Initiative (SEDI) was launched in North America to bring together energy efficiency program providers, manufacturers and governments and to learn from European experiences. SEDI aims to accelerate the market introduction of energy efficient clothes dryer technologies.

EPA ENERGY STAR Emerging Technology Award 2012

EPA created the ENERGY STAR Emerging Technology Award to recognize innovative products that face initial barriers to U.S. market entry, such as high cost or low consumer awareness. As such, these products may not be immediately eligible for consideration within an ENERGY STAR labeling program but still have the potential to significantly reduce greenhouse gas emissions. The ultimate goal of the award is to raise the profile and demand for the technology, so that costs are reduced and the technology becomes more widely available.

EPA elected advanced clothes dryers to be the 2012 Emerging Technology Award category. The Award seeks to encourage manufacturers to bring super efficient clothes dryer technologies to the market within the next year.

On-Going Research and Technology Development

Peaked interest in energy efficient clothes dryers in the last few years has resulted in multiple extensive research and development studies. Table 13 provides a brief overview some on-going clothes dryer research initiatives in the U.S.

Table 13: Summary of Clothes Dryer Research Initiatives

Organization	On-going and Future Research
GE	GE was granted a $24.8 million Advanced Energy Manufacturing Tax Credit the U.S. Department of the Treasury through the Economic Recovery Act, including $4.8 million under the heading, "GE will manufacture a commercially viable Heat Pump Clothes Dryer for residential application in Louisville, Kentucky. GE's expects production of energy-efficiency dryers in the U.S. to commence in 2013.
Porticos	On June 17th, 2010, the DOE awarded $1.7 million to Porticos, a product development engineering firm in Morrisville, NC to develop a "Next-Generation Clothes Dryer (NGCD)" designed to provide equivalent performance with a lower energy expenditure than conventional vented electric clothes dryers. The prototype is based on a novel heat-reclamation scheme (not a heat pump) that aims to use only 50% of the energy of a conventional dryer, place little to not burden on the HVAC system, and dry clothes in the same amount of time as a comparably-sized conventional dryer.
Ecos Consulting (now Ecova)	Ecos Consulting, on behalf of NRDC, conducted research in 2009 on the real-world energy use of clothes dryers, and provided recommendations based off of available savings opportunities. In 2011, Ecos Consulting (now Ecova) conducted additional research assessing the efficiencies of clothes dryers using the amended DOE test procedure, as well as an Ecos-developed test procedure more reflective of real-life conditions. For CLASP, Ecova is expanding both laboratory and field studies of conventional and European heat pump dryers later this year.
NEEA	Northwest Energy Efficiency Alliance (NEEA) is conducting a study of dryer use in 80 households in four states a part of a larger residential sub- metering study to better understand consumer usage behaviors and actual electricity consumption.

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