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Perfect Pairings?

Testing the Energy Efficiency of Matched Washer-Dryer Sets

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Glossary of Terms and Acronyms

Term/Acronym	Definition/Meaning
AHAM	Association of Home Appliance Manufacturers
AHAM Cotton	Association of Home Appliance Manufacturers (AHAM) 100% cotton load of sheets, pillowcases and towels as specified by AHAM HLW-2-2020 and IEC 60456 (2010), Annex C.
Appendix J2	U.S. DOE's Appendix J2 for amended test procedure for consumer clothes washers, specified in 10 CFR Part 430, Subpart B.
CEF	combined energy factor
CFR	Code of Federal Regulations
cu ft	cubic foot or cubic feet
DOE	U.S. Department of Energy
DOE 50/50	DOE-designated textiles for Appendices J2, D1, and D2; comprised of standard-sized momie cloths made of 50 percent cotton, 50 percent polyester.
DOE-rated value	The sum of the hot water and machine energy use of the washer as predicted by Appendix J2 plus the dryer energy use as measured by Appendix D1 or D2.
Eco	A washer-dryer test run with an 8.45 lb. load and Table 3 settings.
ENERGY STAR® program	A partnership between private and public sector organizations and the federal government. The name and mark are registered trademarks owned by the U.S. EPA. Through this partnership, organizations may receive authorization to use one or more of the ENERGY STAR trademarks to identify and promote their certified products and/or to highlight their partnership with ENERGY STAR.
EPA	U.S. Environmental Protection Agency
ES	ENERGY STAR certified residential clothes washers or clothes dryer
FL	front load clothes washer
Heavy-Duty (H-Duty)	A washer-dryer test run with an 8.45 lb. load and Table 3 settings.
HP	heat pump dryer
IMC	initial moisture content
IMEF	integrated modified energy factor
IWF	integrated water factor
lb.	pound or pounds
Max	A washer-dryer test run with a maximum washer load and Table 3 settings.
NEEA	Northwest Energy Efficiency Alliance
NOPR	notice of proposed rulemaking
NPCC	Northwest Power and Conservation Council
NQ	Clothes washers or dryers **not qualified** to ENERGY STAR program certification levels.
RBSA	Residential Building Stock Assessment
RFI/RFIs	request for information/requests for information
RMC	remaining moisture content
RTF	Regional Technical Forum (Advisory Committee of the NPCC)
Small	A washer-dryer test run with a 4.2 lb. load and Table 3 settings.
TL	top load clothes washer
TSD	U.S. DOE technical support document

Executive Summary

Household clothes washers and dryers represent about 7 to 10 percent of a home's total energy use. To date, all major U.S. efforts to reduce energy use of residential laundry equipment have focused on clothes washers and dryers separately, despite almost 70 percent of these appliances being purchased together as matched sets. With this in mind, the Northwest Energy Efficiency Alliance (NEEA) undertook a research project to assess the energy use, efficiency, and cycle time of seven washer-dryer pairs across a range of efficiencies and price points.

Laboratory testing and analysis revealed that the energy use information available from manufacturer-reported DOE ratings generally underestimates the energy use of washer-dryer pairs when tested under more realistic use conditions (i.e., commonly used cycle settings and higher cotton content of the test load). Washer-dryer pairs may use approximately 30 to 60 percent more electricity and 35 to 80 percent more natural gas than their DOE ratings suggest. This is the equivalent of annual electric and gas utility bills of $3 to $6 billion nationally and $96 to $216 million in the Northwest.

This research also reinforces findings from past efforts and informs new opportunities. First, as it relates to test procedures, project results underscore that Appendices D1 and D2 for dryers significantly underestimate energy consumption under realistic use conditions. NEEA recommends a complement to the existing dryer test procedure with supplemental tests, as well as increasing the initial moisture content (IMC) of the test textiles going into the dryer to better account for the amount of water actually left in them when using top load washers.

Second, although reporting cycle time for residential clothes washers and dryers is not required in either washer or dryer protocols, testing revealed stark increases in this measure for the heat pump washer-dryer pairs. Though they use half the energy per pound of laundry of other ENERGY STAR certified washer-dryer pairs and approximately one-third of non-qualified pairs, they take substantially longer to wash and dry typical loads. NEEA recommends cycle time be a reporting requirement, as the extended duration may be a bigger trade-off than many consumers are willing to make for improvements in energy efficiency.

Finally, this research and project test results suggest that timing may be ripe for developing an ENERGY STAR® "Perfect Pairs" program to promote the most efficient washer-dryer matched sets. However, more research is needed to accurately assess the opportunity. Specifically, a larger test sample with more top load washers and standard-sized heat pump dryers will provide more detailed analysis to inform technical specifics for such a program. Additionally, input from various stakeholders (manufacturers, retailers, energy efficiency organizations, etc.) will be integral in crafting a useful platform.

1. Introduction

Over the last decade, the Northwest Energy Efficiency Alliance (NEEA) has contributed significant research and thought leadership on energy efficiency improvements in laundry equipment. Notable efforts include seminal research into test procedures (Foster Porter et al. 2020, Dymond 2017, Denkenberger et al. 2012, Dymond et al. 2012), laundry equipment field research published in the Residential Building Stock Assessment (RSBA) Laundry Study (Hannas and Gilman 2014), extensive lab and field study of heat pump clothes dryers (Dymond 2018), and multiple comment letters to the U.S. Department of Energy (DOE) on test procedures for residential and commercial washers and dryers (NEEA 2020a, 2020b, 2020c, 2019a, 2019b; NEEA et al. 2016).

To build on this progress, NEEA undertook a testing project related to the primary purchase point for washers and dryers: matched pairs. NEEA enlisted an ISO/IEC 17025 certified laboratory to measure the efficiency of seven washer-dryer sets and contracted Kannah Consulting to analyze the collected data. This report documents these efforts and is organized as follows:

- **Section 2 – Rationale and Project Scope –** establishes the project need and focus for this investigation.
- **Section 3 – Methodology –** details the test sample and data collection approach.
- **Section 4 – Results and Key Findings –** provides outcomes including energy use, cycle time, and other technical findings.
- **Section 5 – Conclusions and Recommendations –** examines this study's impact on national and regional energy use estimates, considers test procedure and program implications, and identifies future areas for research.

2. Rationale and Project Scope

NEEA's research (Foster Porter et al. 2020) finds that residential laundry equipment remains an important area of focus for energy efficiency improvement efforts. Even while other appliances (such as refrigerators and dishwashers) have become more efficient over time, the energy use of clothes dryers has not improved nearly as quickly (Mauer and deLaski 2020). Currently, about 7 to 10 percent of a home's total electricity use is from household clothes washers and dryers (NPCC 2021, Flamer 2021), and almost 70 percent of these appliances are purchased at the same time as matched pairs (Horowitz 2014). Consumers value the visual appeal of washer-dryer pairs and can purchase them at a variety of price points, features, styling options, and color finishes (Figure 1).

Figure 1. Examples of Washer-Dryer Matched Pairs

Although these appliances work together to clean and dry household clothing and linens, their efficiencies are rated separately, even when sold together as a set. See Table 1 for the dizzying array of specifications.

Table 1. Summary of Washer and Dryer Mandatory Standard and ENERGY STAR® Specification Levels

Equipment Type		Mandatory Standard (CFR 2021)	ENERGY STAR* (U.S. EPA 2021 & U.S. EPA 2017)	ENERGY STAR Most Efficient (U.S. EPA 2020b & 2020a**)
Clothes Washer	Standard-sized front load (≥ 1.6 cu ft)	1.84 IMEF 4.7 IWF	*> 2.5 cu ft:* 2.76 IMEF 3.2 IWF *≤ 2.5 cu ft:* 2.07 IMEF 3.2 IWF	*> 2.5 cu ft:* 2.92 IMEF 3.2 IWF *≤ 2.5 cu ft:* 2.20 IMEF 3.7 IWF
	Standard-sized top load (≥ 1.6 cu ft)	1.57 IMEF 6.5 IWF	*> 2.5 cu ft:* 2.06 IMEF 4.3 IWF *≤ 2.5 cu ft:* 2.07 IMEF 4.2 IWF	
	Compact top load (< 1.6 cu ft)	1.15 IMEF 12.0 IWF	2.07 IMEF 4.2 IWF	Ineligible
Clothes Dryer	Standard electric	3.73 CEF	3.93 CEF	4.30 CEF
	Standard gas	3.3 CEF	3.48 CEF	3.80 CEF
	Vented compact electric 240 V	3.27 CEF	3.45 CEF	4.30 CEF
	Vented compact electric 120 V	3.61 CEF	3.80 CEF	4.30 CEF
	Ventless 240 V compact electric	2.55 CEF	2.68 CEF	3.70 CEF
All-in-One Washer Dryer	Ventless electric all-in-one washer-dryer	IMF and IWF same as above; 2.08 CEF	IMEF, IWF, and CEF same as above***	Ineligible

Notes: Standard-sized dryers are 4.4 cubic foot (cu ft) capacity or larger; compact dryers are less than 4.4 cu ft. All-in-one washer dryers (also called combination washer-dryers) wash and dry textiles in the same drum. To comply with the mandatory standard or certify to the ENERGY STAR program, equipment must meet or exceed IMEF (integrated modified energy factor) and CEF (combined energy factor) values shown. IWF (integrated water factor) values shown are the maximum allowed. Units for the IMEF are kWh per cycle per cubic foot of basket capacity. IWF is in terms of gallons of water per cycle per cubic foot of basket capacity. CEF is given in pounds of bone-dry textile per kWh. U.S DOE defines some product classes not shown here. They are excluded because there are no products of this type in DOE's compliance database (U.S. DOE 2021a).

*Connected clothes washers and dryers are also allowed an IMEF or CEF adder equal to 5 percent of the base IMEF or CEF as shown in this table. **ENERGY STAR Most Efficient certified dryers must also meet CEF criteria for a supplemental test on the Normal program with highest dryness level setting. These supplemental CEF criteria are not shown here. ***All-in-One washer dryers with water-cooled drying are ineligible for the ENERGY STAR program.

Laundry equipment is rated separately even for the newest washer-dryer pairs that digitally communicate with one another to automatically select the appropriate dryer settings at the completion of the wash cycle.[1] Furthermore, mixed labeling within a pair can be confusing. For example, ENERGY STAR® certified washers are sometimes paired with non-qualifying (NQ) dryers, but consumers may think the entire pair is ENERGY STAR certified. Other times, these appliances have different ENERGY STAR certification marks: an ENERGY STAR Most Efficient certified dryer is sometimes paired with a standard ENERGY STAR certified washer. Consumers are left to determine which mark and appliance matter most.

Furthermore, there is sufficient reason to believe that the energy use of a pair may differ from the energy use expected from the individual ratings of washers and dryers. Findings from prior research (Foster Porter et al. 2020) demonstrate that changing the washer cycle away from the DOE measured cycle results in increases in washer textile remaining moisture content (RMC), which in turn has a significant increase in the energy required to dry them. Additionally, utilizing textiles more representative of real-world settings also increases washer RMC, further driving up drying time and energy use.[2]

Given the importance of washer-dryer pairs as a market segment, NEEA scoped a research effort to answer the following questions:

- When tested under more realistic conditions, how does the energy use of a washer-dryer pair differ from DOE's rated energy use?
- If warranted, could program and/or policy changes help promote the most efficient washer-dryer pairs?

The following two sections document the investigative approach and the results from testing and analysis to answer these research questions.

3. Methodology

3.1. Test Sample

NEEA intentionally selected seven washer-dryer pairs that represent a variety of dryer technologies and expected efficiencies. Five of the seven were manufacturer-designated matched laundry pairs; pairs C and E were the best matches available on the market for those dryer models. Sample sets fall into one of three categories:

- **Set 1 – ENERGY STAR certified front load washers matched with ENERGY STAR certified compact electric heat pump dryers** (ES FL Washer & Compact HP Dryer; pairs A, B, and C)
- **Set 2 – ENERGY STAR certified front load washers matched with ENERGY STAR certified conventional dryers** (ES FL Washer & Conventional Dryer; pair D has an electric dryer and pair E has a gas dryer)

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[1] Two examples are GE's Clean Speak Technology at https://products.geappliances.com/appliance/gea-support-search-content?contentId=18003, and LG's Wash Tower at https://www.lg.com/us/washer-dryer-combos/lg-wkgx201hba-washtower, accessed 6 December 2021.

[2] DOE's test procedure uses standard-sized 50 percent cotton, 50 percent synthetic blend momie textiles (DOE 50/50). Typical consumer loads contain much higher cotton content of different fabrics in a variety of sizes, weights, and bulk.

- **Set 3 – Non-qualifying top load washers matched with non-qualifying conventional dryers** (NQ TL Washer & Conventional Dryer; pair F has an electric dryer and pair G has a gas dryer)

Other factors were considered in the selection process as well. Some pairs were selected because other comparison data were available from prior NEEA projects, and all samples needed to be currently available for sale at the time testing occurred. Complete sample characteristics are in Appendix A. The primary limitation of the test sample is that no pairs with ENERGY STAR certified top loading washers were included, preventing the applicability of research findings to this specific product category.

3.2. Determination of Baseline from Manufacturer-Reported Values

In the U.S., manufacturer-reported energy use of a given washer or dryer is determined based on each appliance's U.S. DOE test procedure results. Appendix J2 is currently used for testing clothes washers (CFR 2015), and Appendices D1 (CFR 2013a) and D2 (CFR 2013b) are used for clothes dryers.[3] While testing of clothes dryers measures only drying energy, the measure of efficiency for clothes washers (integrated modified energy factor or IMEF) is more expansive and includes energy use for water heating (gallons of hot water used), washing machine operation (kWh per cycle), and drying the load (remaining moisture content or RMC of the textiles at the end of the washer cycle). The RMC is expressed as a percent and is defined as the ratio of the weight of water to the bone-dry weight of the textile load.[4] RMC values of standard-sized washers range from 28 to 31 percent for front load washers and 28 to 47 percent for top load washers (U.S. DOE 2021a). In contrast, Appendices D1 and D2 begin dryer testing with textiles at a higher set initial moisture content (IMC)[5] of 57.5 percent and do not account for specific spin characteristics of a paired washer. Table 2 summarizes these test procedure characteristics.

Table 2. Comparison of U.S. Clothes Washer and Dryer Energy Efficiency Test Procedures

U.S. Clothes Washer Test Procedure Appendix J2 (CFR 2015)	U.S. Clothes Dryer Test Procedure Appendices D1 & D2 (CFR 2013a & 2013b)
Water heating energy—estimate from gallons of hot water used	
Clothes washer machine energy—direct measurement during test	
Clothes dryer energy—estimate from clothes washer textile RMC (28 to 47% RMC)	Clothes dryer energy—direct measurement during the test with 57.5% dryer IMC

[3] Appendix D1 *estimates* the effectiveness of automatic termination and is most often used by manufacturers for certifying to U.S. mandatory standards. Appendix D2 *measures* it and is required for ENERGY STAR certification.
[4] Bone-dry weight is the weight of the textiles without any moisture. Specifically, it is defined as a condition of a load of test cloths which has been dried in a dryer at maximum temperature for a minimum of 10 minutes, removed, and weighed before cooling down, and then dried again for 10-minute periods until the final weight change of the load is 1 percent or less. Appendices J2, D1, and D2 contain identical definitions of bone-dry.
[5] RMC and IMC are the same thing (moisture content of the textiles); RMC is test terminology used for the washer (end of cycle) and IMC is test terminology used for the dryer (start of cycle).

This project component analyzed Appendices J2, D1, and D2 reported energy values from DOE's Compliance Certification Database (2021) for the washers and dryers in the test sample. Variation in reported pair energy use when considering different values for the drying energy from the washer test procedure (left column Table 2) and the dryer test procedure (right column Table 2) was also examined.

Specifically, this analysis compared the total energy use of a washer-dryer pair calculated in two ways: 1) as predicted solely by Appendix J2 (sum of water heating energy, active and standby washer machine energy, and dryer energy), and 2) as predicted by a combination of measurements from Appendix J2 and Appendix D1 or D2 (sum of Appendix J2 water heating energy, Appendix J2 active and standby washer machine energy, and Appendix D1 or D2 dryer energy). From this analysis, a baseline reported pair energy use value (termed DOE-rated value) was selected for application in other aspects of this project.

3.3. Laboratory Data Collection

3.3.1. Test procedures, load sizes, and textiles

The ISO/IEC 17025 certified laboratory (lab) measured energy use of washers in the sample utilizing a modified version of DOE's Appendix J2 test procedure (CFR 2015). The lab tested sample dryers using an adapted version of NEEA's version 1.2 dryer test procedure (Dymond 2017). NEEA collected more than 130 dryer tests and 50 washer tests on the sample set. The most recent testing occurred from September 2020 to August 2021, and NEEA leveraged some previously collected data from 2015 to 2018.

Tested load sizes included:

- 8.45 pound (lb.) (typical size defined by Appendices D1 and D2),
- 4.2 lb. (as defined by Test 1 of NEEA's dryer test procedure), and
- Appendix J2-defined washer maximum load.

The two test textiles employed were more representative of typical household loads:

- AHAM/IEC 100 percent cotton textile load (AHAM Cotton) specified in AHAM's washing efficacy test procedure (AHAM 2020) and IEC's washing efficacy and energy efficiency test procedure #60456 (IEC 2010), and
- NEEA-defined Lands' End textiles (Lands' End) (Dymond 2017).

The test plan included two types of testing: washer-dryer pair testing (which accounts for energy impacts of the washer in the dryer) and standalone dryer testing (which uses a fixed IMC at the start of the drying cycle). More details follow.

3.3.2. Washer-dryer pair tests

Washer-dryer pair testing examined energy use in more realistic conditions and compared results to energy use predicted by manufacturer-reported DOE-rated values. To assess the effectiveness of the washer spin cycle on the energy use of the dryer, pairs were measured serially (i.e., loads were dried immediately following the wash cycle) using an AHAM Cotton load or a Lands' End Load (most used AHAM Cotton; see Section 4.3.3). Cycle time and energy use of the test runs were recorded and compared to DOE-rated values. Table 3 provides an overview of test run conditions while Appendix A details individual test runs and baseline values.

Table 3. Washer-Dryer Pair Test Run Conditions

Test Name	Washer Settings	Dryer Settings	Load Size
Eco*	Normal, warm wash, default spin	*Low heat* (As defined by Test 3 of NEEA's dryer test procedure)	8.45 lb.
Heavy-Duty (H-Duty)	Heavy-Duty with defaults (when available)	*High heat* (As defined by Test 4 of NEEA's dryer test procedure)	8.45 lb.
Max	Normal, cold wash, cold rinse, and max spin	*As defined by Appendix D2*	Maximum load size**
Small	Normal, warm wash, default spin	*Medium heat* (As defined by Test 1 of NEEA's dryer test procedure)	4.2 lb.

Notes: *Pair B washer settings for **Eco** differed from the other pairs; washer settings were normal, cold wash, and default spin. Section 4 figure notes indicate when Pair B is omitted from some analyses because comparisons are inappropriate. **As defined by Appendix J2.

3.3.3. Standalone dryer tests

To understand better the benefits and limitations of testing the washer-dryer pairs serially, the lab also performed complementary standalone tests of the dryers using a fixed 62 percent IMC at the start of the dryer cycle (per NEEA's dryer test procedure instructions). Dryer settings, load sizes, and textiles were otherwise the same as those shown in Table 3 so that direct comparisons could be made between the fixed IMC and the variable washer RMC results from serial testing.

4. Results and Key Findings

The following subsections detail findings from manufacturer-reported, DOE-rated efficiency values and analysis of laboratory test data. A discussion of other technical findings that inform test procedure recommendations and program opportunities is also provided.

4.1. Determination of Baseline from Manufacturer-Reported Values

Two possible energy use ratings are available to characterize washer-dryer pair energy use. They are derived from manufacturer-reported DOE ratings and often differ significantly from one another. Figure 2 compares these two ratings for Set 1 (ES FL Washer & Compact HP Dryer), Set 2 (ES FL Washer & Conventional Dryer), and Set 3 (NQ TL Washer & Conventional Dryer)

The gray dot shown in Figure 2 is the washer-dryer energy use as estimated by Appendix J2 alone. In the same figure, the blue dot is the sum of the hot water and machine energy use of the washer predicted by Appendix J2 and the dryer energy use as measured by Appendix D1 or D2. The difference between these two ratings is particularly striking for conventional dryers, especially ENERGY STAR certified pairs D and E and non-qualifying pair F. On average, the blue energy use value (which uses data from Appendix J2 and Appendix D1 or D2) is 44 percent higher for conventional dryers than the gray value (Appendix J2 alone).

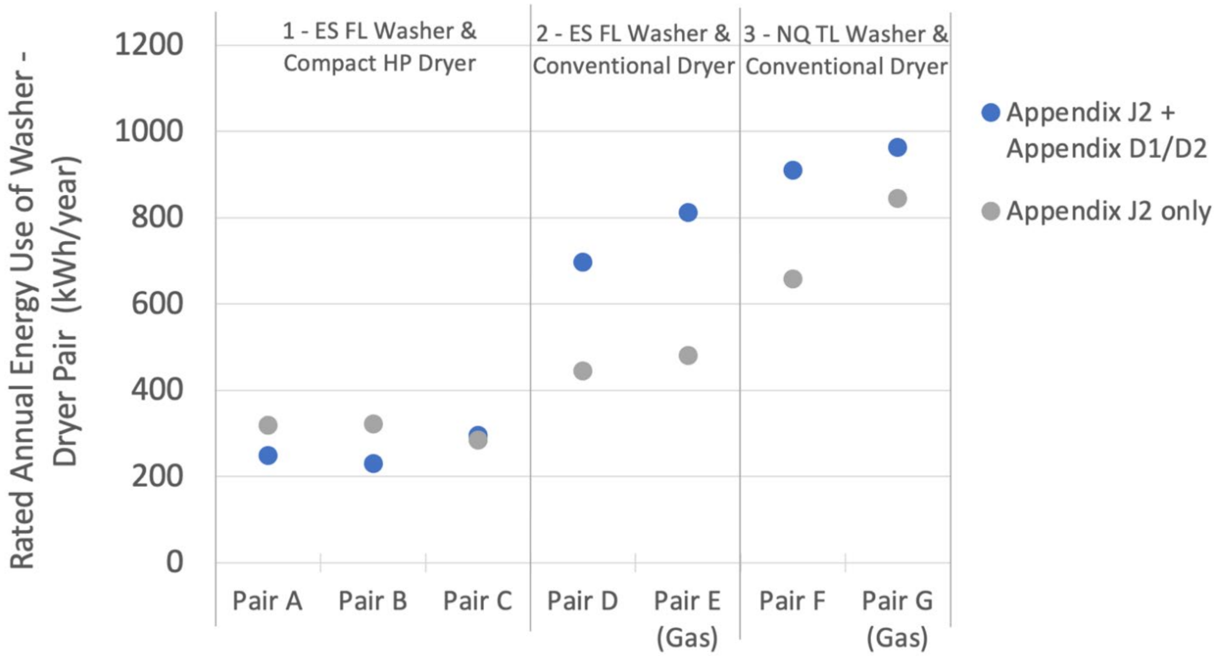

Figure 2. Manufacturer Reported DOE-Rated Energy Use of Pairs in Test Sample

Notes: ES = ENERGY STAR certified; FL = front load; HP = heat pump; NQ = non-qualifying; TL = top load.

When quantifying pair energy use, utilities and other stakeholders could select either one of these ratings to represent the energy use of a given washer-dryer pair. Assuming that the efficiencies of most dryers are relatively similar to one another, and that the most important attribute of a pair is how well the washer spins the water out of the load (to reduce the energy use of the dryer), then the gray dot could be selected to represent the energy use of a pair. Assuming instead that predicting washer-dryer pair energy use should include a measure of the dryer's efficiency and better account for realistic initial moisture contents (IMCs) of textiles going into the dryer, the blue dot may be the best measure of the efficiency of a pair. However, the energy use represented by the blue dot ignores possible variation in IMC of the dryer load (due to remaining moisture content (RMC) changes in washer test cycles). Unfortunately, neither representation from available data accounts for how much energy a washer-dryer pair may together use in the real world, as each has distinct limitations.

The energy use represented by the blue dot was used to examine washer-dryer pair energy use in this report, as it leverages information from both the washer (Appendix J2) and dryer (Appendix D1 or D2) test procedures. Referred to as the **DOE-rated value** in the remainder of this report, it is the sum of the hot water and machine energy use of the washer predicted by Appendix J2 and the dryer energy use as measured by Appendix D1 or D2.

4.2. Washer-Dryer Pair Energy Use

This analysis compared washer-dryer pair energy use during testing with the DOE-rated value for average-sized loads (**Eco** and **Heavy-Duty** tests), as well as washer-dryer pair energy use for small loads (**Small**) and Appendix J2-defined maximum loads (**Max**). All analysis is from test runs that used the AHAM Cotton textile load.

4.2.1. Washer-Dryer Pair Average Load Size Energy Use

Figure 3 illustrates results from serial test runs using an average-sized load (8.45 lb.) with two different settings, one intended to characterize a typical energy-efficient cycle (**Eco**) and one to characterize a more energy-intensive cycle (**Heavy Duty**/**H-Duty**).

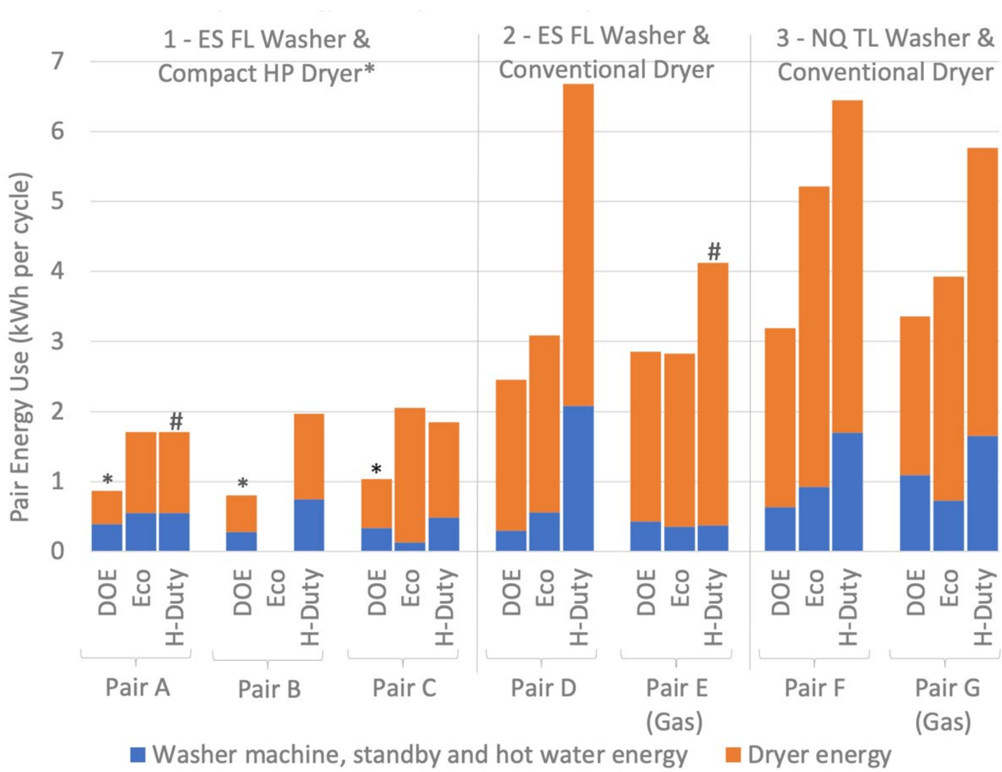

Figure 3. DOE-Rated Energy Use of Pairs Compared to Serial Washer Dryer Tests with an Average Size AHAM Cotton Textile Load

Notes: *DOE rating is with a smaller load than **Eco** and **H-Duty** tests. #No Heavy-Duty washing setting was available. ES = ENERGY STAR certified; FL = front load; HP = heat pump; NQ = non-qualifying; TL = top load; DOE is the manufacturer-reported DOE-rated value for energy use as defined in Section 4.1. Pair B **Eco** is excluded because the washer cold wash temperature setting was inconsistent with Table 3 (i.e., its water heating energy use was not comparable to the other pairs).

Key observations include:

- For the heat pump pairs with available data (pairs A and C), changing settings from **Eco** to **Heavy Duty** does not matter much for energy use.
- For both ENERGY STAR certified and non-qualified pairs with conventional dryers (pairs D, E, F, and G), the **Heavy Duty** setting significantly increases energy use relative to DOE-rated values. This increase is due to more hot water use in the wash cycle and the fast-dry setting for the dryer.

- With the **Eco** setting, conventional ENERGY STAR certified pairs used a similar amount of energy to their DOE-rated value.
- For some tests, changes in rank order of the washer-dryer pairs occurred. For example, ENERGY STAR certified pair D used more energy during the **Heavy-Duty** test than both non-qualified pairs (pairs F and G).
- Non-qualified top load washers paired with conventional dryers used more energy than their DOE-rated value. This increase is dominated by the higher than rated drying energy and results from these two dryers being rated under the Appendix D1 test procedure but tested in this study using NEEA's version 1.2 dryer test procedure. This underscores NEEA's field research findings that Appendix D1 significantly underestimates energy consumption in real-world use (Hannas and Gilman 2014, p. 15).

4.2.2. Washer-Dryer Pair Maximum and Small Load Size Energy Use

Results of **Max** and **Small** washer-dryer pair tests with the AHAM Cotton load are illustrated in Figure 4.

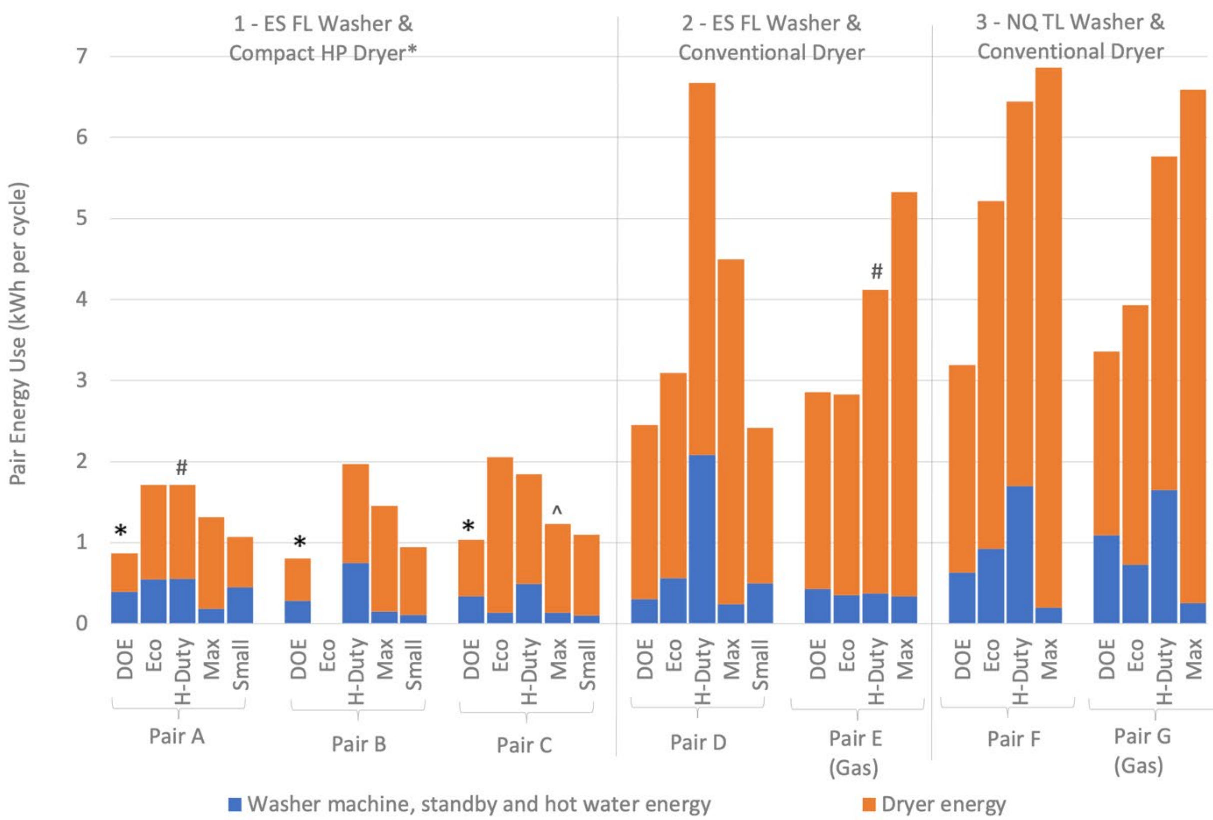

Figure 4. DOE-Rated Energy Use of Pairs Compared to Four Washer-Dryer Tests with AHAM Cotton

Notes: *DOE rating is with a smaller load than **Eco** and **H-Duty** tests. #No Heavy-Duty washing setting was available. ^Appendix J2-defined maximum load similar to average 8.45 lb. load.
ES = ENERGY STAR certified; FL = front load; HP = heat pump; NQ = non-qualifying; TL = top load; DOE is the manufacturer reported DOE-rated value for energy use as defined in Section 4.1. Pair B **Eco** is excluded because the washer cold wash temperature setting was inconsistent with Table 3 (i.e., its water heating energy use was not comparable to the other pairs).

Key observations about these data include:
- The pair energy use per cycle of a **Max** serial test with J2-defined maximum load size is generally (but not always) higher than the **Heavy-Duty** cycle with an average-sized load (8.45 lb.).
- Hot water use in the **Heavy-Duty** cycle test is an important energy use impact.
- For pairs A, B, C, and D, the energy use per cycle with a **Small** (4.2 lb.) AHAM Cotton load is very similar to their DOE-rated value.

4.2.3. Categorical Comparison of Washer-Dryer Pair Energy Use

Analysis of the categorical efficiency of washer-dryer pairs included taking the ratio of the combined washer-dryer energy (in kWh) for a given test to the weight of bone-dry textiles washed and dried during that test (in pounds). Because of the differences in drum/basket sizes of the three categories, the average load size for the **Max** test differed by category (Table 4), while the **Eco** and **Heavy-Duty** tests had an 8.45 lb. load size for all categories.

Table 4. Average Max Load Size by Sample Category

Pair Category	Pairs	Average of Max Load Size*
Set 1 – ES FL Washer & Compact HP Dryer	A, B, and C	9.5 lb.
Set 2 – ES FL Washer & Conventional Dryer	D and E	18.4 lb.
Set 3 – NQ TL Washer & Conventional Dryer	F and G	16.7 lb.

Notes: *As defined by Appendix J2.

Figure 5 shows a categorical average of these kWh per pound ratios for three washer dryer pair tests with the AHAM Cotton load and **Eco**, **Heavy-Duty** and **Max** settings. Note that a lower number (kWh per pound) is better. On a per pound basis, washer-heat pump dryer pairs (Set 1) are the most efficient at washing and drying laundry using approximately 0.2 kWh per pound. This is half the energy per pound of the other ENERGY STAR certified washer-dryer pairs (Set 2) and approximately one-third of energy use per pound of the non-qualified pairs (Set 3).

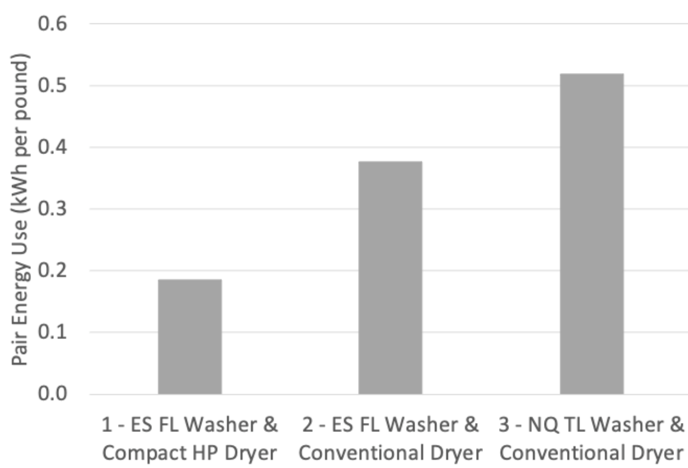

Figure 5. Categorical Average of Pair Energy Use in kWh per Pound with AHAM Cotton Textile for Eco, Heavy-Duty, and Max

Notes: ES = ENERGY STAR certified; FL = front load; HP = heat pump; NQ = non-qualifying; TL = top load.
Details of the **Eco**, **Heavy-Duty**, and **Max** tests are further described in Section 3.3.1.

4.3. Other Technical Findings

4.3.1. Washer RMC and Fixed Dryer IMC in Appendices D1 and D2

Figure 6 summarizes the data comparing the tested washer RMC to its manufacturer-reported RMC (U.S. DOE 2021) and the required dryer IMC of 57.5 percent in Appendices D1 and D2.

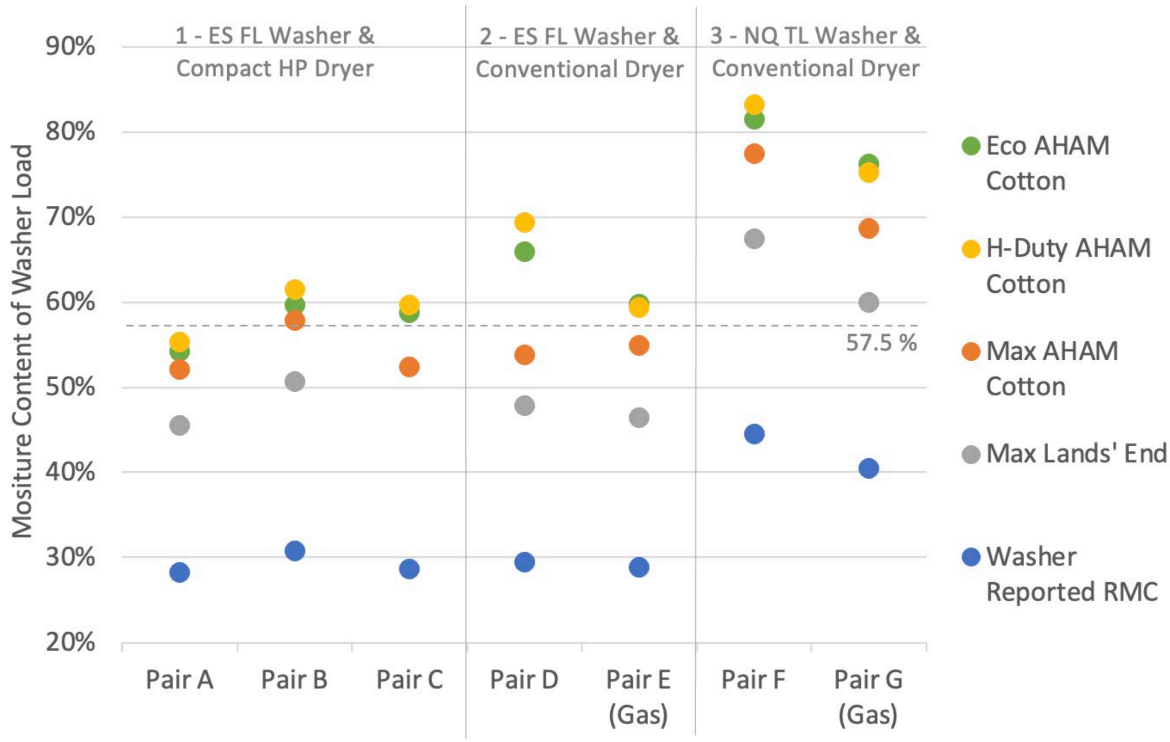

Figure 6. Moisture Content of Washer Load for Washer-Dryer Tests Compared to Dryer IMC and Manufacturer-Reported Washer RMC Values

Notes: ES = ENERGY STAR certified; FL = front load; HP = heat pump; NQ = non-qualifying; TL = top load.
Washer Reported RMC is manufacturer-reported remaining moisture content (RMC) for that washer (U.S. DOE 2021).
Textiles for **Eco**, **H-Duty,** and **Max** tests are noted in the figure. Details of these tests are further described in Section 3.3.1.

These results are consistent with NEEA's prior clothes washer research (Foster Porter et al. 2020) that found larger load sizes yield lower washer RMCs, and that a textile load of 100 percent cotton yields higher RMCs than the 50 percent cotton, 50 percent synthetic blend momie textiles (DOE 50/50) specified in Appendices J2, D1, and D2. New findings include:

- Average washer RMC was 60 percent for ENERGY STAR certified front load washers (pairs A through E) tested under **Eco** and **Heavy-Duty** cycles, which is highly similar to the dryer IMC of 57.5 percent specified in Appendices D1 and D2.
- Average washer RMC for non-qualified top load washer pairs (F and G) tested with **Eco** and **Heavy Duty** was 79 percent, more than 20 percentage points higher than the dryer 57.5 percent IMC specified in Appendices D1 and D2.

Together, these data indicate that DOE's Appendices D1 and D2 effectively approximate the RMC of realistic loads coming from ENERGY STAR certified front load washers but may underestimate RMC of realistic loads coming from non-qualified top load washers. Specific conclusions about ENERGY STAR certified top load washer pairs cannot be made. However, a reasonable assumption is that the resulting RMC of this product category is likely somewhere between ENERGY STAR front load and non-qualifying top load RMC levels.

4.3.2. Dryer Energy Use with Changes in Washer RMC (Dryer IMC)

The dryer energy use of **Eco** and **Heavy-Duty** washer-dryer pair tests was compared to the tests performed with a fixed IMC of 62 percent (per NEEA's dryer test procedure), but identical in load size, textile type, and settings to the serial washer-dryer pair tests.[6] Figure 7 illustrates percent increases in dryer energy use per cycle and percent increases in water removed from the textiles due to the change in washer RMC from the fixed 62 percent IMC to the washer RMC of the washer-dryer pair serial **Eco** and **Heavy-Duty** tests.

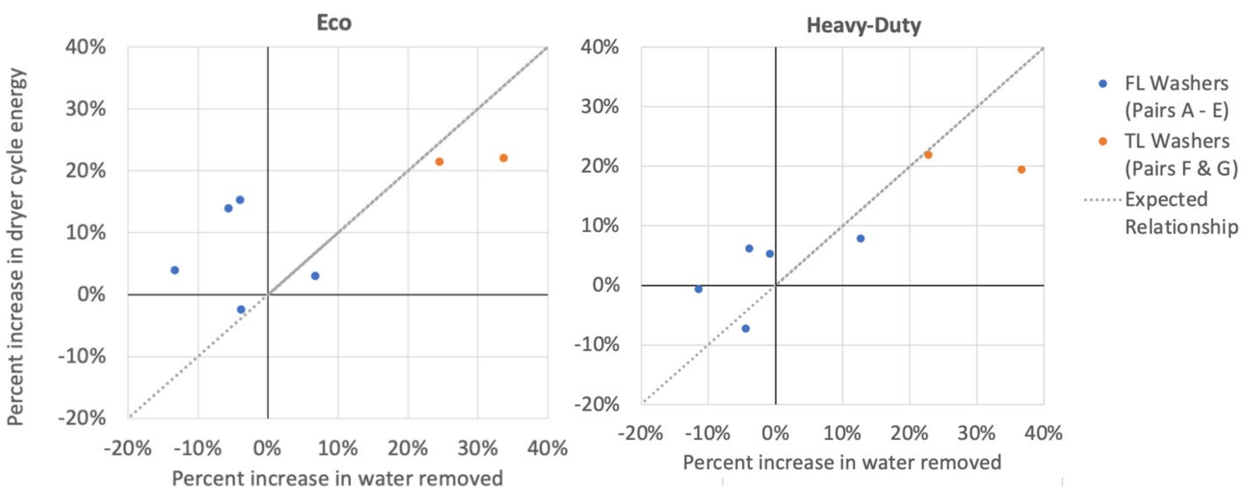

Figure 7. Percent Increase of Dryer Energy per Cycle and Percent Increase of Water Removed from 62 Percent Dryer IMC to Washer-Dryer Pair Test IMC for Eco and Heavy-Duty (AHAM Cotton)

Notes: FL = front load; TL = top load
Textiles for **Eco**, **H-Duty** tests are AHAM Cotton. Details of these tests are further described in Section 3.3.1.

Key observations about these data include:

- For ENERGY STAR certified front load washer pairs (A through E), NEEA's dryer test procedure cannot detect changes in dryer energy use with small differences in dryer IMC. Although variation in dryer cycle energy use was observed, it was not statistically significant. The dryer automatic termination algorithm variation appears to be a stronger influence than the energy use differences associated with changes in dryer IMC. Given NEEA's dryer test procedure is based on the Appendix D2 test procedure, small differences in IMC of the dryer load are expected to be undetectable with Appendix D2 as well.

[6] For this comparison, some dryers were compared to the results of another dryer of the same make and model (e.g., dryer 25a and 25b). Some dryers were compared to the "replacement model" (e.g., dryer 48 and 53).

- For top load non-qualifying washer pairs (F and G), the percent increase in water removed was different enough from 62 percent dryer IMC that the increase in dryer cycle energy was statistically significant. However, the amount that the dryer energy use changed was different than expected based on the percent increase in water removed (observed changes in washer RMC). Further investigation is needed to identify accurate dryer energy use changes associated with RMC increases observed with top load washers. Given that Appendices D1 and D2 have a similar dryer IMC (57.5 percent), these top load washer findings are expected to apply to that test procedure as well.

The primary conclusion from these data is that testing front load washer and their dryer pairs in the serial fashion used in this investigation may not yield statistically significant differences in dryer energy use results. However, considering a serial approach for top load washers may be warranted to more accurately capture energy use of dryers coupled with top load washers. More specific recommendations address this issue in section 5.2.

4.3.3. AHAM Cotton Compared to NEEA-defined Lands' End Load

NEEA collected test data on both representative textiles—AHAM Cotton and Lands' End—for some test conditions. Washer-dryer pairs with these types of data are shown in Table 5.

Table 5. Washer Dryer Pair Test Run Conditions with Both AHAM Cotton and Lands' End Textiles

Washer-Dryer Pair Test	Washer-Dryer Pairs Tested
Eco	A, B, and C
Heavy-Duty	A, B, and C
Max	A, B, D, E, F, and G
Small	A, B, C, and D
Other*	C

Notes: *This is the large load and settings defined by Test 2 of NEEA's dryer test procedure. For more detail on this test, see Appendix A. Note that for Pair B, the **Eco** wash settings were set to cold wash for both the AHAM Cotton and Lands' End textiles. This is an exception to Table 3 of this report.

Washer-dryer pair cycle energy use of test runs using the AHAM Cotton load is almost identical to the energy use when tested with the Lands' End load. Figure 8 plots the sum of washer and dryer cycle energy use with AHAM Cotton as a function of the sum of the washer and dryer cycle energy use with Lands' End textiles. A trend line with the y-intercept at the origin is included (because when there is zero cycle energy use for one textile, there is zero for the other).

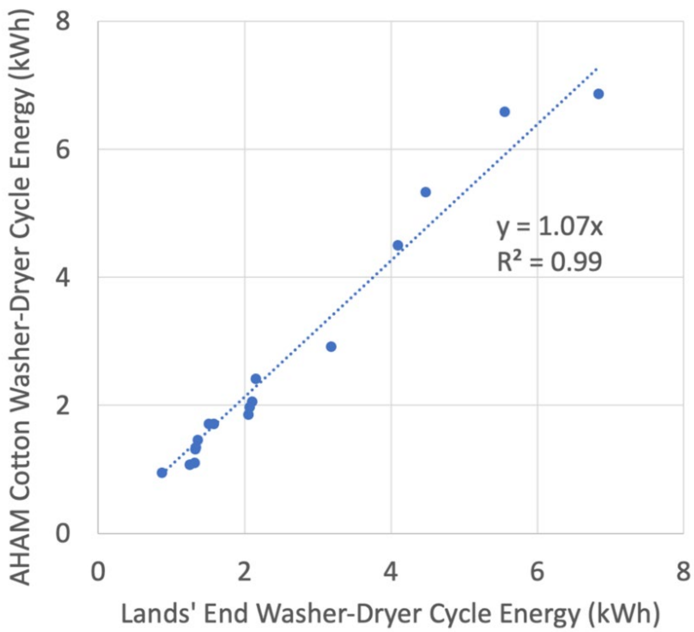

Figure 8. Washer-Dryer Pair Energy Use per Cycle with Lands' End Test Load Compared to AHAM Cotton with Y-Intercept at Origin

Key observations include:

- For a given load size, the energy use of AHAM Cotton is on average 2 percent higher than the comparable Lands' End load. This produces a slightly greater than one slope in the Figure 7 trendline (m=1.07). However, additional analysis revealed that this increase is not statistically significant.
- The AHAM Cotton load generally starts the drying cycle with a slightly higher IMC than the Lands' End load (because of its moderately higher cotton content) but is somewhat easier to dry near the end of the cycle because it has less diversity of thickness of textiles compared to those found in the Lands' End load. These two effects seem to offset one another in the dryer's energy use, yielding very similar dryer energy use for both textiles. Ultimately, the outcome is highly similar results for the pair washer-dryer energy use.

<u>These data confirm that the AHAM Cotton textile reasonably approximates the more realistic textiles of the Lands' End load for washer-dryer pairs. Adopting the AHAM Cotton textile more broadly in laundry equipment testing could increase the representativeness of tests while still enabling repeatable and reproducible results.</u>

4.3.4. Cycle Time of Heat Pump Dryer Pairs

To inform incentive program consumer messaging and marketing of high efficiency heat pump dryer pairs, cycle times of ENERGY STAR front load washer and compact heat pump dryer pairs were compared to the cycle time of other washer-dryer pairs in the sample. The absolute cycle time of the washer and dryer separately and together as a pair were compared and then analyzed by the average pounds of textile washed and dried per minute of cycle time for the three washer-dryer categories in the sample.

Figure 9 shows the mean and range of the wash cycle time for four tests (AHAM Cotton **Eco**, AHAM Cotton **Heavy-Duty**, AHAM Cotton **Max,** and Lands' End **Max**) for the three groups of washer-dryer pairs in the sample. Figure 10 does the same for dryer cycle times. Figure 11 illustrates the combined washer-dryer cycle time. Note that for cycle time, lower values (i.e., shorter cycle times) are better.

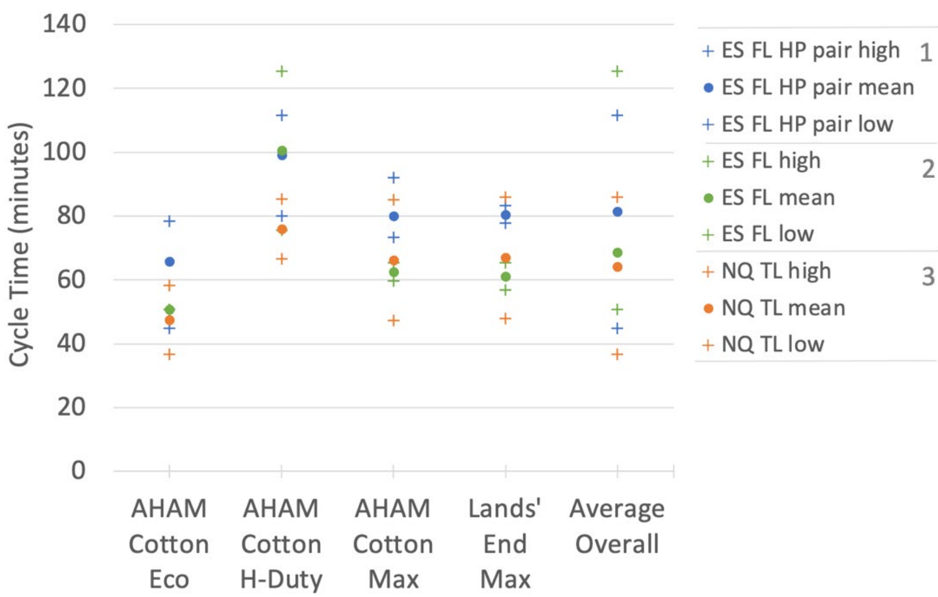

Figure 9. Mean and Range of Washer Cycle Times for Washer-Dryer Pair Tests Performed

Notes: ES = ENERGY STAR certified; FL = front load; HP = heat pump; NQ = non-qualifying; TL = top load.
Textiles for **Eco**, **H-Duty,** and **Max** tests are noted in the figure. Details of these tests are further described in Section 3.3.1.

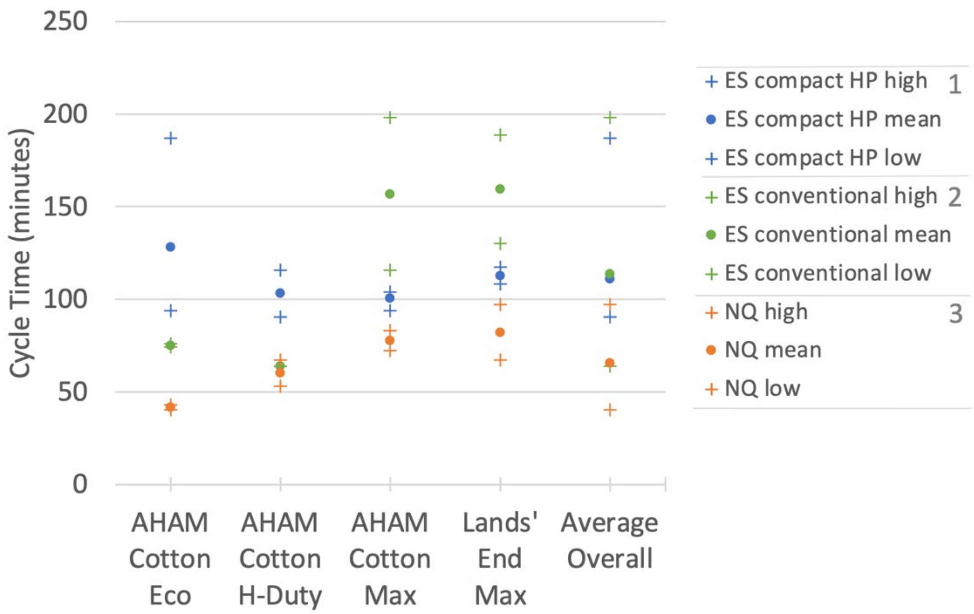

Figure 10. Mean and Range of Dryer Cycle Times for Washer-Dryer Pair Tests Performed

Notes: ES = ENERGY STAR certified; HP = heat pump; NQ = non-qualifying.
Textiles for **Eco**, **H-Duty,** and **Max** tests are noted in the figure. Note that **Max** dryer tests are with Appendix D2 settings, which generally lowers drying temperature and lengthens drying time for conventional ENERGY STAR certified dryers. Details of these tests are further described in Section 3.3.1.

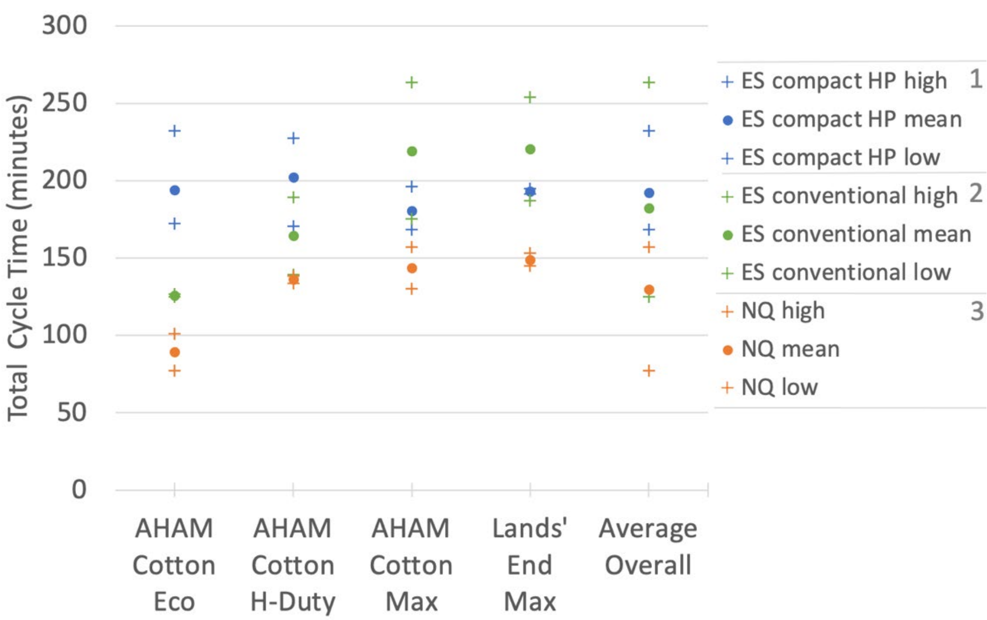

Figure 11. Mean and Range of Washer-Dryer Cycle Times for Washer-Dryer Pair Tests Performed

Notes: ES = ENERGY STAR certified; HP = heat pump; NQ = non-qualifying.
Textiles for **Eco**, **H-Duty,** and **Max** tests are noted in the figure. Note that **Max** dryer tests are with Appendix D2 settings, which generally lowers drying temperature and lengthens drying time for conventional ENERGY STAR certified dryers. Details of these tests are further described in Section 3.3.1.

Key observations of this washer-dryer cycle time data include:

- Washer-dryer cycle times for compact heat pump pairs are, on average, longer than the ENERGY STAR certified and non-qualified conventional pairs in almost all tests.
- Dryer cycle time is the dominant driver in the overall washer-dryer pair cycle time.
- For conventional dryers, settings heavily influence cycle time.

There are other notable findings for discussion. First, the compact heat pump pairs take longer to wash and dry an average-sized 8.45 lb. load (**Eco** and **H-Duty**) compared to all the conventional pairs. This is likely due to the load size relative to the basket/drum size given the heat pump dryers in the sample are compact. On average, heat pump pairs were 68 minutes longer on the **Eco** test and 38 minutes longer on the **Heavy-Duty** test than the ENERGY STAR certified pairs. Furthermore, heat pump pairs were 105 minutes longer on the **Eco** test and 66 minutes longer on the **Heavy-Duty** test than the non-qualified pairs.

Second, for the loads that are normalized to the washer basket size (**Max**), the heat pump pairs have a shorter cycle time average than the average of the ENERGY STAR certified conventional pairs. This is in part because the dryer settings for this test are according to Appendix D2, which tends to lower the temperature and lengthen drying times for conventional ENERGY STAR certified dryers. Cycle times of heat pump pairs tested with the **Max** AHAM Cotton Load were an average of 80 minutes shorter than cycle time of ENERGY STAR certified pairs with conventional dryers. Similarly, heat pump pair cycle times measured with the **Max** Lands' End load averaged 27 minutes shorter than the average cycle time of ENERGY STAR certified pairs with conventional dryers. However, the average **Max** load size for the heat pump pairs (9.5 lb.) was significantly smaller than the average **Max** load sizes for the ENERGY STAR certified pairs (18.4 lb.) and non-qualified conventional pairs (16.7 lb.) due to their larger drums/baskets.

Finally, further analysis of cycle time of washer-dryer pairs included taking the ratio of the combined washer-dryer cycle time (in minutes) for a given test to the number of pounds of bone-dry textiles washed and dried during that test. This analysis included averaging the ratios for the three AHAM Cotton tests described above (**Eco**, **Heavy-Duty**, **Max**) for each of the three sample categories of washer-dryer pairs (Figure 11). Note that a lower number (minutes per pound) is better. Also included as an overlay in Figure 12 is the washer and dryer energy use for each category in kWh per pound for the identical set of tests (for details, see Section 4.2.3). Even though heat pump washer-dryer pairs are the most efficient category to wash and dry a pound of textile (0.2 kWh/lb.), they take an average of seven minutes longer than the ENERGY STAR certified conventional washer-dryer pairs and an average of 11 minutes longer per pound than the non-qualified pairs.

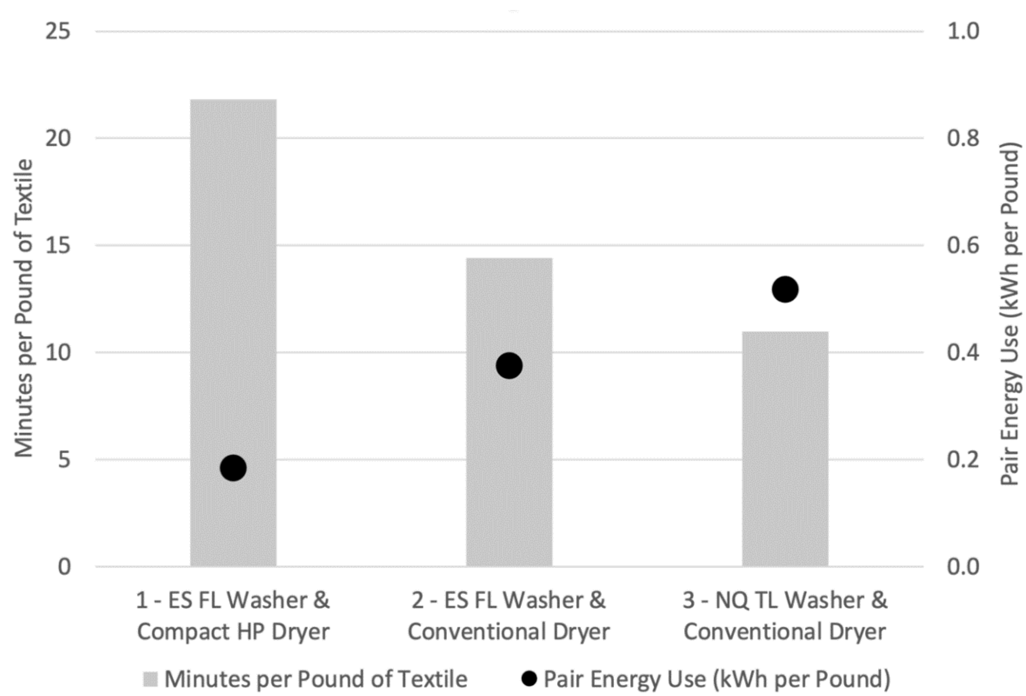

Figure 12. Categorical Average of Pair Cycle Time in Minutes per Pound of AHAM Textile for Eco, Heavy-Duty, and Max

Notes: ES = ENERGY STAR certified; FL = front load HP = heat pump; NQ = non-qualifying; TL = top load.
AHAM Textile used for **Eco**, **H-Duty,** and **Max** tests. Note that **Max** dryer tests are with Appendix D2 settings, which generally lowers drying temperature and lengthens drying time for conventional ENERGY STAR certified dryers. Details of these tests are further described in Section 3.3.1. Section 4.2.3 describes the methodology for calculating pair energy use shown on the right vertical axis.

In summary, even though the washer-compact heat pump dryer pairs are highly efficient, washing and drying an average-sized (8.45 lb.) load takes significantly longer compared to conventional washer-dryer pairs. Additionally, the cycle time required to wash and dry per pound of textile is also significantly higher than conventional washer-dryer pairs.

5. Conclusions and Recommendations

This section applies project findings to various efforts where NEEA serves as an active stakeholder in energy efficiency for laundry equipment.

5.1. Impacts to National and Regional Energy Use Estimates

This research revealed that the energy use of a washer-dryer pair differs from DOE's rated energy use. This section aims to quantify national and regional energy use impacts. National energy use was calculated by estimating the 2027 stock of washer-dryer pairs with an 8.45 lb. AHAM Cotton load and two washer-dryer setting combinations (Eco and Fast in Table 6). These two scenarios represent a range of possible real-world washer-dryer pair energy use and consumer energy cost, with Eco as low energy use scenario and Fast as the high energy use scenario. Note that the Eco scenario is the same as the Eco test, while Fast uses Normal wash settings with a quick, high heat drying cycle.

Table 6. Washer-Dryer Energy Use Scenario Details

Scenario	Washer Settings	Dryer Settings	Load Size
Eco	Normal, warm wash, default spin	Low heat (As defined by Test 3 of NEEA's dryer test procedure)	8.45 lb.
Fast	Normal, warm wash, default spin	High heat (As defined by Test 4 of NEEA's dryer test procedure)	8.45 lb.

Figure 13 compares these two scenarios to national estimates using the DOE-rated value of energy use for washer-dryer pairs (defined in Section 4.1). Similar estimates were prepared for the Northwest region (adjusted from national numbers based on population, the alternate share of gas dryers in use, and differences in energy prices). Regional results were lower in magnitude, but otherwise nearly identical to national results. Appendix B details assumptions used to calculate all estimates.

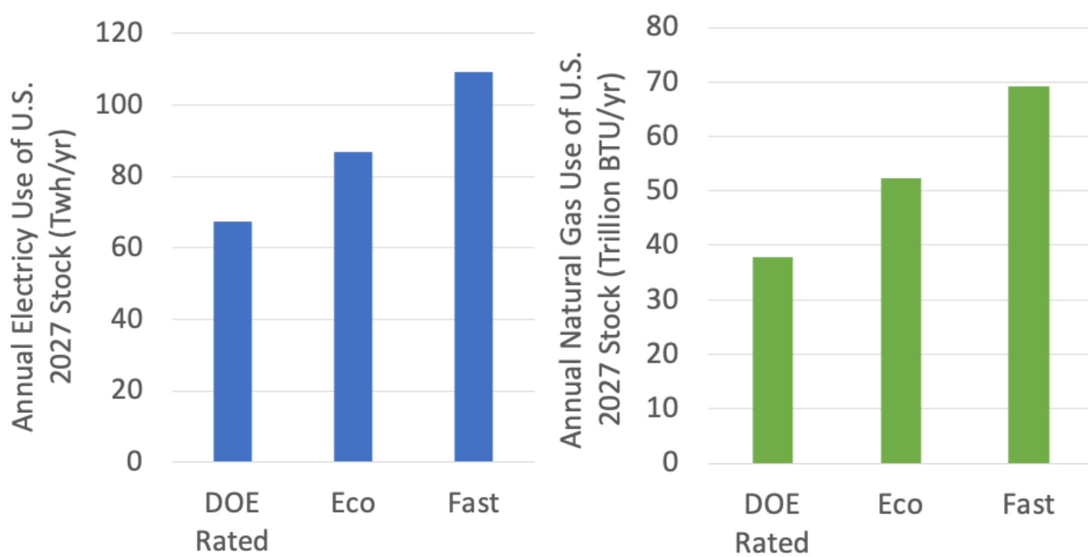

Figure 13. National Electricity and Gas Energy Use of Washer-Dryer Pairs (2027 Stock)

Analysis of the energy use characterized by the Eco and Fast scenarios reveals that washer-dryer pairs may use approximately 30 to 60 percent more electricity and 35 to 80 percent more natural gas than their DOE ratings suggest. The increase in energy use is driven primarily by higher dryer energy use. ENERGY STAR certified washer-dryer pairs contribute about 30 percent of the increase in dryer energy use for Eco and about 50 percent for Fast. This equates annually to \$3 to \$6 billion electric and gas utility bill increases nationally and \$96 to \$216 million increases regionally. Table 7 documents the range of increases over energy estimates based on DOE ratings.

Table 7. Increases in Energy Use of 2027 Washer-Dryer Stock Compared to DOE-Rated Values

	Annual Increase over DOE Rating	Eco (low energy use scenario)	Fast (high energy use scenario)
National	Electricity Increase	29%, 20 TWh	62%, 42 TWh
	Natural Gas Increase	38%, 15 trillion BTU	83%, 31 trillion BTU
	Annual Utility Bill Increase	$3 billion	$6 billion
Regional	Electricity Increase	29%, 830 GWh	64%, 1,900 GWh
	Natural Gas Increase	37%, 180 billion BTU	83%, 400 billion BTU
	Annual Utility Bill Increase	$96 million	$216 million

These estimates strongly suggest that there is justification for policy and/or program changes to improve testing approaches that measure laundry equipment energy use, as well as an opportunity to promote the most efficient washer-dryer pairs. The next section discusses specific test procedure improvements and opportunities for existing and potential laundry equipment efficiency programs.

5.2. Test Procedure, Policy, and Program Recommendations

5.2.1. Clothes Washer and Clothes Dryer Test Procedures

Although the focus of this work is washer-dryer pairs, there are several findings to inform recommendations on stand-alone test procedures for clothes washers and dryers. These data support NEEA's current recommendations to DOE on both the clothes washer and the clothes dryer test procedures:

- *Measuring and reporting cycle time.* Cycle time varies significantly among both washers and dryers and is an important attribute for consumers. DOE does not require reporting cycle time for dryers (DOE 2021c) but did propose to measure cycle time for washers (DOE 2021b). Our findings in Section 4.3.4 support the importance of both measuring and reporting cycle time for washers and dryers so that consumers can reasonably consider possible trade-offs between energy efficiency and cycle time.
- *Considering a more realistic textile for testing.* Stakeholders, including NEEA, have long expressed concerns about the lacking representative nature of the DOE-specified textile used to measure the efficiency of laundry equipment. Research in Section 4.3.3 reveals that the energy use of a washer-dryer pair tested with the AHAM Cotton load is highly similar to more complex real-world loads (such as Lands' End) and makes a good energy consumption test textile candidate given its wide industry acceptance and demonstrated repeatability and reproducibility.

Specific recommendations for each appliance test procedure follow.

5.2.1.1. Clothes Washer Test Procedure

The two key recommendations specific to the clothes washer test procedure (currently Appendix J2) both focus on increasing the representativeness of the drying energy measurement in the clothes washer test procedure. The first recommendation focuses on the more effective measurement of washer RMC (remaining moisture content). The second discusses the opportunity to adjust the drying energy use of realistic textiles mathematically.

This research further supports NEEA's 2020 findings (Foster Porter et al. 2020) that the Appendix J2 clothes washer test procedure can be improved by measuring drying energy use across all tests in the washer test procedure, including multiple temperature settings and load sizes. In particular, test cycles measuring RMC should include warm water wash settings, as these settings generally showed a pattern of substantially increased energy use compared to their DOE published rating (Section 4.2). In its 2021 notice of proposed rulemaking (NOPR), DOE proposed to make this change in the forthcoming Appendix J clothes washer test procedure (DOE 2021b). DOE, however, did not propose to change the prescribed textile load to the AHAM Cotton load.

To more accurately account for energy to dry realistic textiles in Appendix J2, stakeholders could consider mathematically adjusting the washer RMC of the DOE 50/50 momie test textiles to an RMC of more realistic cotton textiles. This could be a future change to the clothes washer test procedure, or it could be adjusted from data currently reported from the existing Appendix J2 test procedure. In its 2020 laundry report (Foster Porter et al. 2020, Section 4.2 *Textile Type*), NEEA developed a linear mathematical relationship between Appendix J2-defined textiles and AHAM Cotton textiles across a broad range of washer efficiency levels and technology types. This relationship has an excellent R-squared value (greater than 0.95) and can be used to adjust the washer RMC of the DOE 50/50 textiles to the RMC expected with AHAM Cotton textiles. Using this relationship would increase the drying energy calculated in the washer test procedure. This approach has the following advantages:

- *It more realistically accounts for clothes washer impacts on drying energy use.* The test procedure includes drying energy use in the clothes washer efficiency metric, but that energy use is based on the very low washer RMC associated with Appendix J2-specified DOE 50/50 test load. Most typical laundry loads have a much higher cotton content, so mathematically adjusting the washer RMC before calculating the expected drying energy of a test load would better account for typical use.
- *It increases alignment between the Appendix J clothes washer drying energy use calculation and the measured Appendix D2 clothes dryer energy use.* As discussed in Section 4.1, the drying energy calculated in the Appendix J2 clothes washer test procedure is often much lower than the energy consumed by a typical dryer (tested by either Appendix D1 or D2). This is because the dryer IMC (initial moisture content) of 57.5 percent used in the dryer test procedures more accurately reflects a typical real-world textile. Using NEEA's mathematical adjustment to increase the RMC of the washer before calculating drying energy would make these drying energy values (*estimated* in the washer test procedure and *measured* in the dryer test procedure) more similar to one another.
- *It adds no additional test burden.* Because this calculation would affect only the post-processing of the data, it could be automated and represent no additional test burden.

Together, these changes will increase the representativeness of the clothes washer test procedure, better align DOE's washer and dryer test procedures, and will not add significant test procedure burden.

5.2.1.1. Clothes Dryer Test Procedures

There are two opportunities to improve the clothes dryer test procedure: The first recommendation is to complement the existing dryer test procedure with supplemental tests. The second is to increase the dryer IMC to better account for top load washers.

For Appendices D1 and D2, this research confirms NEEA's previous findings (NEEA 2019a) that various dryer settings significantly change the dryer's energy use. Changes in dryer settings also contribute to rank order shifts for the washer-dryer pairs (Section 4.2). Policymakers can consider adding additional tests with high heat to the dryer test procedure to capture this variation. The ENERGY STAR Most Efficient program already employs an extra test as associated qualification levels using the "most dry" setting on the Normal program (EPA 2020a), and this research suggests consideration of high heat (Fast) dryer settings instead of, or in addition to, this alternate dryness level test.

Research also showed that the current IMC in the dryer test procedure (57.5 percent) is appropriate for dryers coupled with ENERGY STAR certified front load washers but not for dryers coupled with top load washers (Section 4.3.1). This indicates the need to consider adjusting the current IMC to reflect the average market split between front load and top load washers more accurately. A better representation of IMC in the dryer test procedure will provide more realistic dryer energy measurements.

Market research, project data, and proposed test procedure improvements lay the framework for changes to existing heat pump dryer programs and suggest an opportunity to create something new for the ENERGY STAR laundry equipment platform.

5.2.2. Heat Pump Dryer Incentive Program

Since 2012, NEEA has dedicated resources to researching and promoting heat pump dryers; however, market penetration for this product category is still less than one percent of total sales (see Appendix C for details). Some consumer wariness may be in part to how well the product will perform. Cycle time research detailed in section 4.3.4 revealed that washing and drying an average-sized (8.45 lb.) load in the washer-heat pump dryer pairs takes significantly longer than conventional washer-dryer pairs. Furthermore, the cycle time required to wash and dry a pound of textile is also significantly higher. The time to complete a washing-drying cycle is a critical performance variable for some consumer demographics (e.g., families). Given these findings, we have two key recommendations for utilities and other energy efficiency stakeholders:

- *Expand consumer marketing and education efforts.* Many heat pump dryer pairs on the market today are high efficiency but come with cycle time trade-offs that may not be acceptable to all consumers. We encourage consumer education about this cycle time difference to prevent consumer dissatisfaction with heat pump dryer purchases.

- *Work with manufacturers to encourage development of higher capacity, vented heat pump dryers with optional fast cycle times.* The compact size (< 4.4 cu ft), ventless design, and lack of electric resistance boost all contribute to longer cycle times for this dryer category (TeGrontenhuis 2016). Total washer-dryer cycle time is also longer due to the smaller capacity of the heat pumps' matching clothes washers that extend washing time relative to higher-capacity washers. Working with manufacturers to encourage development of standard capacity vented heat pump dryers with electric resistance boost options would help address the cycle time issues uncovered in this study, ultimately making heat pump dryer technology more accessible and desirable to a broader range of consumers.

5.2.3. ENERGY STAR "Perfect Pairings" Program

This research suggests the potential for an ENERGY STAR program dedicated to promoting the most efficient matched washer-dryer sets. The reasons are simple: More than two-thirds of residential clothes washers and dryers are purchased at the same time as a matched pair, and they use significantly more energy than their DOE ratings suggest under typical consumer wash-dry conditions (Section 5.1). Elements of this research serve to inform a base framework for a "Perfect Pairings" platform to promote the most efficient matched washer-dryer sets. Recommendations include:

- *A supplemental washer-dryer test* with Normal program, warm wash, and default spin washer settings and Fast (high heat) dryer settings to complement existing standalone tests for washers and dryers. This supplemental testing could be performed in a serial fashion or as added data collection instructions to each existing standalone appliance test. The dryer high heat test complements the lower heat settings typically employed for the Appendix D2 test for dryers and gives consumers a range of cycle time and efficiency for the washer-dryer pair. This supplemental test is similar to the ENERGY STAR Most Efficient certification criteria for both washers and dryers.
- *An alternative test load* using AHAM Cotton to represent more realistic consumer laundry loads. Adding supplemental tests using the AHAM Cotton load as part of the "Perfect Pairings" criteria could increase the representativeness of tests while still maintaining repeatable and reproducible results.
- *A fresh ENERGY STAR marketing approach* for residential laundry equipment. There is an opportunity for ENERGY STAR, energy efficiency stakeholders, manufacturers, and retailers to coordinate a substantial promotion effort for matched washer-dryer sets.
- *Cycle time data collection, cycle time reporting, and consumer education on cycle time* for reasons noted above in Section 5.2.2.

There is a notable gap in information for a "Perfect Pairings" program. Realistic tests of top load washer-dryer pairs have higher washer RMC (dryer IMC) than the current Appendices D1 and D2 (Section 4.3.1). An alternate test with higher dryer IMC for pairs with top load washers is needed for accurate dryer energy use estimates. The exact approach will require additional research since top load ENERGY STAR certified pairs were not included in the test sample (Section 4.3.2).

5.3. Suggested Areas for Additional Research

This investigation builds on NEEA's previous efforts, offering additional information to understand better the actual energy use of residential laundry equipment in real-world settings. Several opportunities for additional research emerged under this study. First, a larger test sample will reveal better estimates, particularly for ENERGY STAR certified pairs with top load washers. Also, this study did not include washer-dryer pairs that digitally communicate with one another to automatically select drying cycle settings at the end of the wash cycle. These could be investigated further to assess whether this communication has energy-saving benefits. This information could help inform metrics for a "Perfect Pairings" ENERGY STAR program, as well as recommendations for future test procedure modifications.

Secondly, the heat pump dryers examined as part of this analysis were all considered compact (less than 4.4 cu ft), which made comparison among the three categories of washer-dryer pairs more difficult. Because compact dryers are inherently less efficient than standard-sized dryers, isolating the impact of the heat pump from the smaller size when considering energy efficiency and cycle time was challenging. Additional testing of standard-sized or nearly standard-sized heat pump dryer pairs could help isolate the effects of the heat pump technology from drum/basket size impacts.

Finally, additional analysis is needed to determine if the incremental savings with a "Perfect Pairings" program are distinctive from standalone programs for washers and dryers. However, the opportunity to influence a dominant dual point of purchase moment suggests that it may be a better way to communicate the benefit of ENERGY STAR certified laundry equipment with consumers.

6. References

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Appendix A: Test Data

Appendix B: National and Regional Energy Estimates Assumptions

Section 5.1 of the report calculated annual energy use estimates for three different scenarios, DOE-rated, Eco, and Fast. DOE-rated is based on manufacturer-reported DOE ratings of the washer-dryer pairs in the sample. Eco and Fast scenarios are intended to represent a range of possible real-world energy use and are based on lab tests of washer-dryer pairs in the sample with settings defined in Table 5 of Section 5.1. To develop national and regional energy and utility bill estimates, data from the washer-dryer pairs in the test sample were used to represent identified market groups (Table B.1). Due to the very low sales of heat pump dryers, this market group was excluded from the estimates.

Table B.1 Sample Washer-Dryer Pairs Representing Market Groups

Sample Pair Lab Data (This Study)	Represented Market Groups
***Pair Energy Use:* Average of Pairs D and E** ENERGY STAR® certified front load washer and ENERGY STAR certified conventional dryer (pair D has an electric dryer and pair E has a gas dryer)	• ENERGY STAR Most Efficient certified front load washer and ENERGY STAR certified conventional dryer (gas and electric) • ENERGY STAR certified front load washer and ENERGY STAR certified conventional dryer (gas and electric)
***Washer Energy Use:* Average of Washers in Pairs D, E, F, and G** ENERGY STAR certified front load washers and non-qualified top load washers ***Dryer Energy Use:* Average of Dryers in Pairs D and E** ENERGY STAR certified conventional dryers	• ENERGY STAR certified top load washer and ENERGY STAR certified conventional dryer (gas and electric)
***Pair Energy Use:* Average of Pairs F and G** Non-qualifying top load washer and non-qualifying conventional dryer (pair F has an electric dryer and pair G has a gas dryer)	• Non-qualifying top load washer and non-qualifying conventional dryer (gas and electric)

To calculate the energy consumption of a washer-dryer pair, the product of two quantities was taken: 1) the number of cycles per year (295 from CFR 2015) and 2) the total per cycle energy use measured or calculated for a given scenario. That was scaled that to the annual national energy use of washer-dryer pair sales using the following information and assumptions:

- National sales of washers of 9,700,000 (EPA 2020c)
- 60 percent of washer market are sold with a matched dryer and are considered matched pairs (conservative assumption)

- 25 percent of the washer market is ENERGY STAR certified top load; 25 percent of the market is ENERGY STAR certified front load; 50 percent of the market is non-qualified top load (EPA 2020c and RTF 2021)
- ENERGY STAR certified washers are always paired with ENERGY STAR certified dryers
- 18 percent of dryers sold nationally are gas (EPA 2020c)
- Electric water heating only (simplifying assumption)
- Gas dryers only use gas (simplifying assumption)

Then, the following additional information and assumptions were used to develop 2027 stock energy use and utility bill estimates:

- Equipment lifetime of 15 years (assumption)
- No population growth (simplifying assumption)
- National electricity rate $0.138/kWh; national natural gas rate $1.22 /therm

National data was scaled to the region by adjusting for population, the alternate share of gas dryers sold, and differences in energy prices:

- Population scaling to the region using 3.9% total U.S. population
- Regional electricity rate of $0.113/kWh
- Regional natural gas rate of $1.28/therm
- 6% of dryers sold regionally are gas (RTF 2021)

Results are summarized in Section 5.1 of the report.

Appendix C: NEEA Heat Pump Dryer Sales Data

NEEA participates in the ENERGY STAR Retail Products Platform (ESRPP) to transform consumer product markets with a midstream, retailer-focused strategy. ESRPP program implementers coordinate closely with ENERGY STAR and work directly with corporate-level buying teams of national retailers to provide midstream incentives on qualified energy-efficient products. As part of the ESRPP program, NEEA collected clothes dryer sales data for the Northwest region, and estimates that these data represent approximately 70 percent of all units sold in the Northwest (Table C.1.)

Table C.1 Share of Northwest Sales by Dryer Product Category

Year	Total ESRPP Sales	Percent Sales of Heat Pump Dryers	Percent Sales of ENERGY STAR Most Efficient Certified Dryers*	Percent Sales of ENERGY STAR Certified Dryers**	Percent Sales of Non-Qualified Dryers
2021 YTD***	205,675	0.5%	0.5%	42.2%	57.8%
2020	280,440	0.4%	0.5%	43.8%	56.2%
2019	259,373	0.2%	0.5%	42.3%	57.7%
2018	229,528	0.1%	0.4%	41.7%	58.3%

Notes: * Includes heat pump dryers. ** Includes ENERGY STAR Most Efficient and heat pump dryers. *** Data through end of quarter three.