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# THE BIG PICTURE:
## ULTRA HIGH-DEFINITION TELEVISIONS COULD ADD $1 BILLION TO VIEWERS' ANNUAL ELECTRIC BILLS

*Project Manager:*
Noah Horowitz

*Consultant:*
Ecos Research, Portland, OR
Chris Calwell
Gregg Hardy
David Cadier

*Report edited by:*
Pat Remick

*NRDC reviews by:*
Pierre Delforge
David Goldstein
George Peridas
Kala Viswanathan

*External reviews by:*
Verena Radulovic, USEPA
Alex Chase - Energy Solutions
Nick Leritz - Northwest Energy Efficiency Alliance

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*NRDC Chief Communications Officer:* Lisa Benenson
*NRDC Deputy Directors of Communications:* Michelle Egan and Lisa Goffredi
*NRDC Policy Publications Editor:* Mary Annaïse Heglar
*Design and Production:* www.suerossi.com

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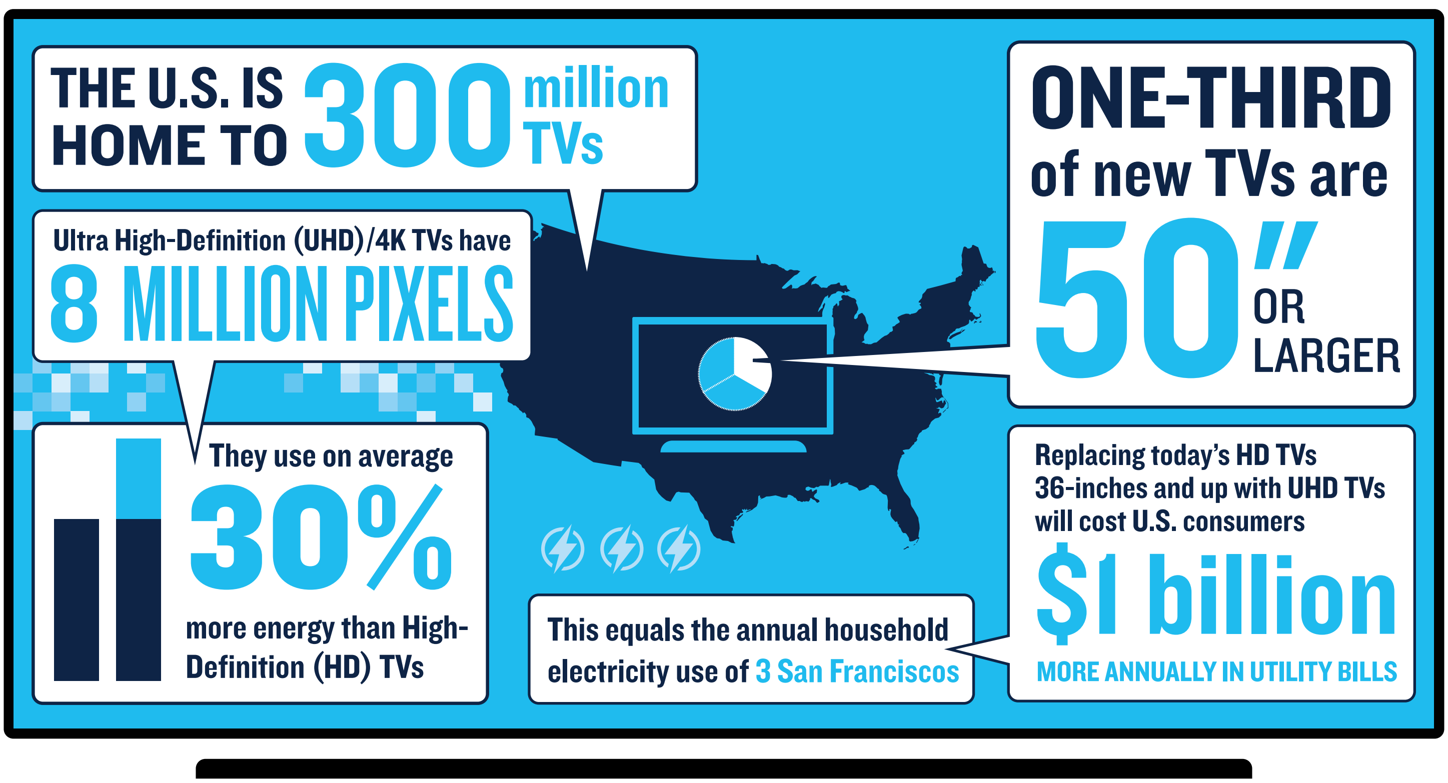
# EXECUTIVE SUMMARY

With an estimated 300 million installed televisions in the United States—almost one per person—it is clear that Americans love their televisions, and many of them are constantly seeking bigger and better models. The newest variety quickly entering the market is known as ultra high-definition (UHD) due to its superior picture quality, with 8 million or more pixels; sometimes these are called 4K TVs because the images are about 4,000 pixels wide, with four times as many pixels as a high-definition (HD) television. Unfortunately, our analysis shows current UHD models use on average about 30 percent more energy than HD models of the same size. As the shift to UHD televisions is now in its early stages, there is still time for manufacturers to incorporate more efficient designs and components into all new models and prevent much of this potential additional electricity use and resultant pollution.



Going forward, consumers will likely be buying new UHD/4K televisions instead of an HD version for all models 36 inches and larger. As the higher resolution provided by 4K TV will not be readily noticeable by consumers on television screens smaller than 36 inches, they likely will stay with HD for these smaller screen sizes. Once this transition is completed, we estimate U.S. consumers will need to pay an extra $1 billion annually to operate their new TVs unless further energy efficiency improvements are made. In fact, the increased energy use of UHD televisions could potentially undo some of the hard-earned television energy savings achieved over the past decade due to a combination of government labeling programs—ENERGY STAR© and the yellow EnergyGuide label—providing consumers with more information about television energy consumption, utility rebates for energy-saving models, and mandatory standards in California that removed the least efficient models from the market.

As noted earlier, UHD televisions offer four times the picture resolution of HD televisions and are commonly referred to as 4K TVs. The acronym UHD has often been used interchangeably with 4K, but UHD capability involves much more than picture resolution. Essentially, all UHD televisions will have 4K or greater resolution, but not all 4K TVs will deliver the full range of UHD capabilities. Additional features sometimes include more dramatic contrast, bolder colors, and Internet connectivity, each of which can potentially increase energy consumption. At the same time, technology advances have led manufacturers to incorporate such energy-saving features as automatic brightness control and advanced backlight controls that can dynamically respond to the lighting conditions in the room and the scene being viewed, respectively, in order to reduce energy use.

Prior to this study conducted by the Natural Resources Defense Council (NRDC) and its consultant, Ecos Research, very little was known about the precise energy impact of the recent changes in the television market and the technology advancements that are occurring. In this study, we analyzed public databases of UHD television energy use and market share sales data, and we performed power use measurements on 21 televisions representing a cross-section of 2014 and 2015 models. Our testing focused on 55-inch TVs because they are the most prevalent size and represent the best value among UHD televisions on the market today.

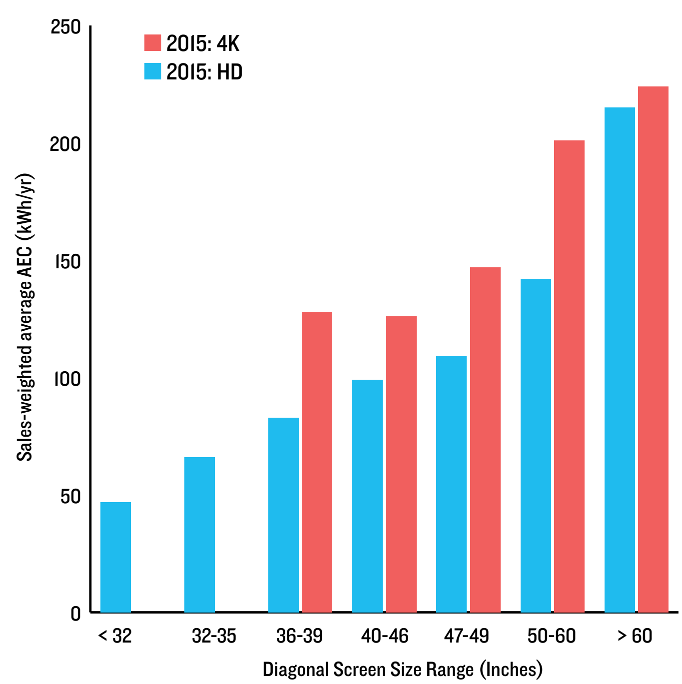
We found that UHD televisions use an average of 30 percent more power than HD televisions of a similar size (see Figure ES-1). However, there were dramatic differences in the power consumption among models of the same size, with the least efficient model we tested using almost three times more power during active operation than the most efficient models. This indicates that the technology already exists to make energy-saving improvements to the most inefficient UHD televisions. Improvements to the energy efficiency of UHD and 4K televisions are in their infancy as our modeling showed only a 4 percent reduction in the energy use of 2015 models from similar-sized 4K TV 2014 models.

In addition, our analysis indicates that the size of television screens is growing quickly, as manufacturers promote them as the best vehicles for optimum viewing of 4K content. Almost one-third of all new televisions being sold today have a screen size of 50 inches or greater, which is important from an energy standpoint as the amount of power used by a television normally increases with screen size. However, this is not always true; some of the most efficient 55-inch 4K TVs we tested use less power than 50-inch models, even though they have roughly 20 percent more screen area.

We also modeled a scenario whose starting point was the assumption that all of America's 300 million televisions were using the same amount of energy as today's HD televisions. What would happen if each of these sets larger than 36 inches was replaced by today's 4K televisions? We found the national impacts would include:

- 8 billion kilowatt-hours (kWh) in additional electricity use per year, or as much electricity as 2.5 large (500 megawatt) power plants produce annually. That is three times the amount of electricity consumed by all the homes in San Francisco each year.
- $1 billion in additional annual costs to consumers to operate their televisions.
- 5 million extra metric tons of carbon dioxide pollution emitted annually due to the additional electricity use.

**Figure ES-1: Comparison of UHD and HD TV Annual Energy Use by Screen Size**



## KEY TEST FINDINGS

We also tested UHD TVs on the market in 2014 and 2015 to determine the energy consumption of various features and settings, including:

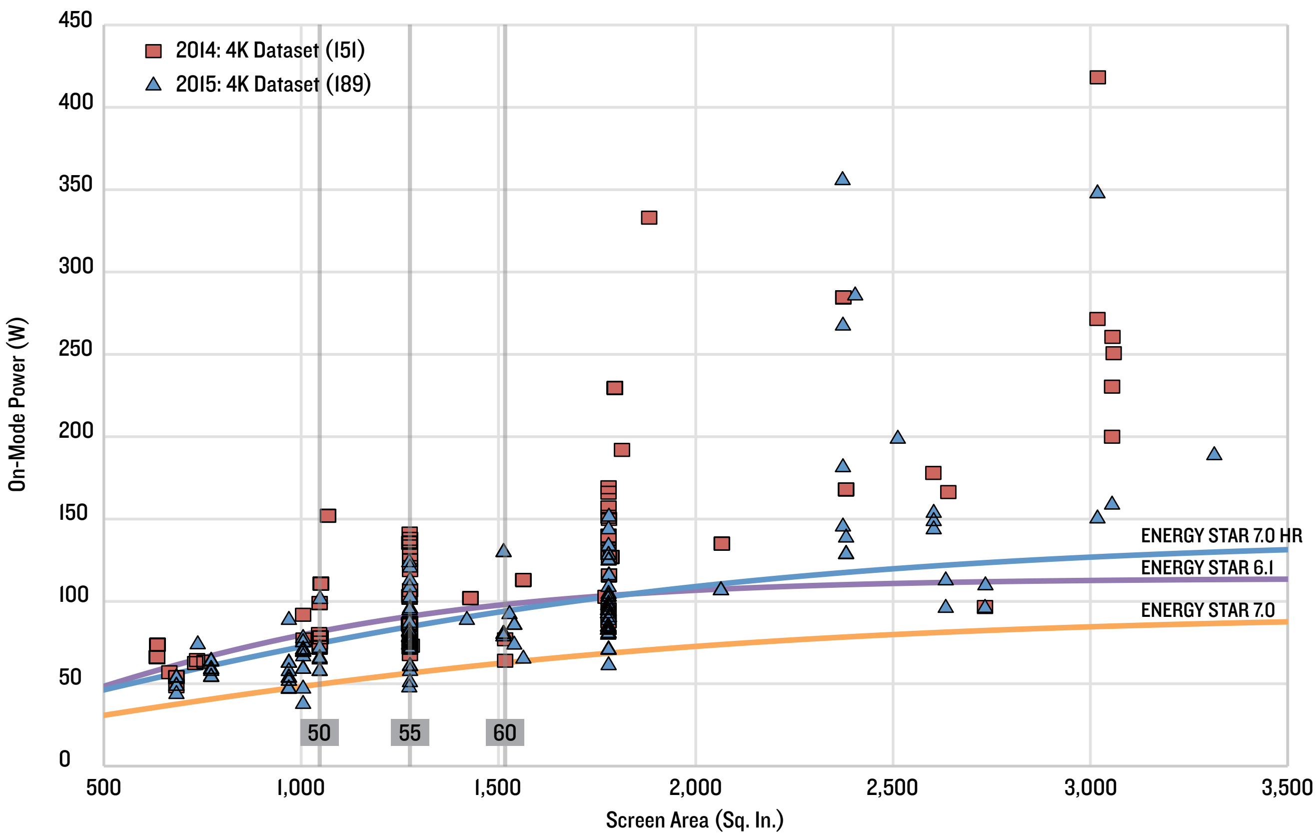
**ON-MODE POWER:** We measured the amount of electricity consumed when televisions are turned on for active viewing and found that some models consume more than 2.5 times as much power as others with the same screen size. The least efficient designs are most often found in the largest screen sizes, and some models consume more electricity annually than a new midsize refrigerator.

At the other end of the spectrum, several UHD TV models already qualify for the ENERGY STAR label, which is reserved for the top 25 percent of all televisions in terms of energy efficiency and is often used as the eligibility criterion for utility rebates. Other UHD TVs could also earn the label with minor modifications.

Figure ES-2 shows how the reported power use for these UHD TVs compares with the maximum qualifying levels for on-mode power in the current ENERGY STAR Version 6.1 and the new Version 7 specification effective October 30, 2015. Above 60 inches, 4K power use rises dramatically. Meanwhile, the U.S. Environmental Protection Agency (EPA) provided an almost 50 percent additional power allowance (adder) for 4K televisions to qualify for its ENERGY STAR Version 7. (When EPA set the specification, there were few UHD models on the market, and the data at that time indicated that a 50 percent additional power allowance was warranted. More models are on the market today, and some have made sufficient efficiency improvements that qualify for ENERGY STAR without this allowance—or to come very close.) The higher energy use levels are shown in the curve labeled ENERGY STAR 7.0 HR, where HR stands for high resolution.

**AUTOMATIC BRIGHTNESS CONTROL (ABC):** From our testing of 50-inch to 55-inch televisions, we found that enabling the ABC feature, which adjusts screen brightness in real time in response to changes in room light levels, had a huge impact on energy consumption, causing TVs to use half as much power, on average, as they otherwise would. However, the actual energy reduction varied widely among models, ranging from 17 percent to 93 percent. The most efficient televisions had ABC implemented by default (meaning it arrived enabled in consumers' homes without them having to take any action), while none of the least efficient televisions did. For reasons that are unclear, some manufacturers chose not to even offer the ABC feature or did not enable it by default, resulting in a lost opportunity for significant energy savings. In some cases, failing to ship

**Figure ES-2: Reported 4K TV Power Use Relative to ENERGY STAR Qualifying Levels (HR indicates the high-resolution allowance provided in ENERGY STAR Version 7)**



the TV with ABC enabled meant the manufacturer missed a chance to otherwise qualify for an ENERGY STAR label and potential utility rebates.

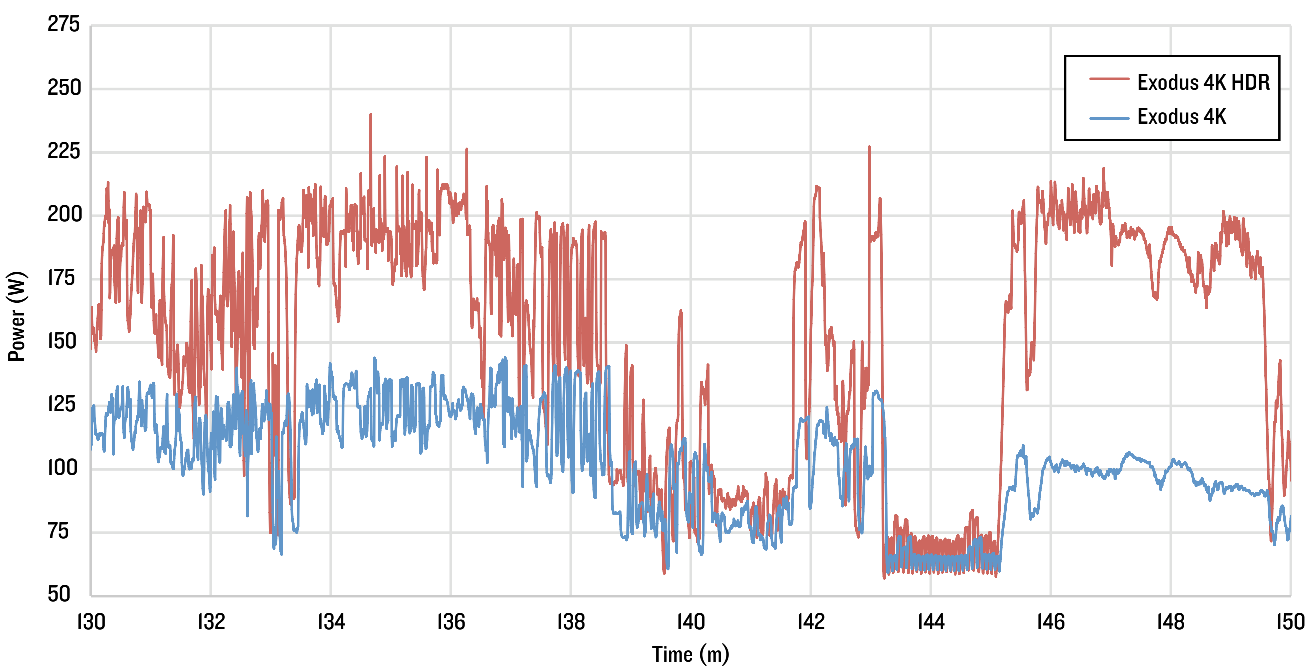
**SMART/INTERNET-CONNECTED TELEVISIONS:** Prior to this research it was not well understood how much power "smart" televisions use when the consumer thinks the television is turned off but in reality it remains connected to the Internet. These televisions are increasingly popular (about 60 percent of new television sales today) because consumers can stream content from services like Netflix directly to their television without the need for a computer or supplemental streaming device. However, this can lead to designs that have a high-energy-consuming quick start mode, which allows the television to boot up more quickly after the consumer turns it back on. The good news is that our testing identified models from Samsung and LG that used less than one-half watt in standby mode while still booting up quickly (in less than 7 seconds) when turned back on. However, models from Sharp and Sony were much slower to start up and could use far more power in standby mode if consumers decide at a later time to enable the quick-start option. One television consumed a whopping 37 watts for six hours a day in standby with quick-start enabled, even though the television appeared to be turned off.

**HIGHER-RESOLUTION CONTENT:** Feeding a 4K television, a higher-resolution (4K) version of HD video material did tend to increase energy use by an average of 10 percent, but there were large differences between models. Meanwhile, streaming higher-resolution content via the Internet instead of playing it from a disc did not make a significant difference in energy use, which is good news as people increasingly stream content over the Internet.

**HIGH DYNAMIC RANGE (HDR):** Some of the 4K televisions on the market today are capable of producing superior picture quality (e.g., brighter whites, darker blacks, and superior contrast ratios) when they receive HDR content. These televisions, generically referred to as 4K HDR or HDR-capable UHD TVs, are expected to be heavily promoted to, and sought by, consumers in the near future. As no information was available about the potential energy impact of playing HDR content on these models, we tested two movies on the Samsung UHD TV model UN55JS9000, first with the 4K version of content and then with the 4K HDR-encoded edition. On average, the HDR version of the movie caused this television to use 47 percent more energy than the non-HDR version (Figure ES-3). Even though the power use of the two versions was similar for very dark scenes, it was dramatically higher (often double) on extremely bright scenes, as evident by the energy usage spikes in the graph below of a 20-minute segment from *Exodus—Gods and Kings*.

The lesson from this testing is that HDR could have a bigger impact on television energy use than the jump to 4K by itself, particularly in combination with the other, optional UHD features and the continuing push for ever-bigger screens. If the least efficient design strategies for implementing 4K dominate sales and HDR becomes

**Figure ES-3: On-mode Power Testing on Samsung Model UN55JS9000 Playing 4K and 4K with HDR Content**



widespread, average 4K TV energy use could more than double from today's HD models. More testing is needed to determine if the very large power increase we observed is representative of the 4K HDR models entering the market. (Note: We performed testing on only one TV model due to the limited budget of this study and the market scarcity of 4K HDR models and HDR-encoded content.)

## CONCLUSIONS AND RECOMMENDATIONS

While our analysis shows the potential for very large deleterious energy, environmental, and economic impacts due to the shift to 4K/UHD televisions, the good news is that today's best designs consume very little extra power when operating, compared with their similar-size HD counterparts. In addition, most (but not all) of the smart TVs use very little standby power (0.5W or less) and are able to reboot within 10 seconds or less. Given that the technology exists and is already being incorporated into the most efficient UHD television models, our collective challenge is to ensure that the vast majority of the market moves in the direction of greater energy efficiency. Complicating the matter are new UHD features that have not yet been widely implemented, such as 4K televisions with HDR, whose power use may rise significantly when displaying HDR-encoded content.

As Table ES-1 shows, there are steps that consumers can take to lower their utility bills, as well as changes that manufacturers can incorporate to reduce the energy waste of their televisions. However, there also is a need for policymakers and government agencies to act to ensure that our televisions do not waste electricity, leading to an increased need to burn polluting fossil fuels to generate it. A critical element is ensuring that the tests used to measure the energy use of new televisions are continually updated by the U.S. Department of Energy so that they capture the amount of consumption from such new developments as 4K video shot with HDR cameras.

Our recommendations for measures that will ensure progress are summarized in Table ES-1.

**Table ES-1: Ways to Improve the Energy Efficiency of 4K Televisions**

| Consumers | TV Manufacturers/Industry | Policymakers/Government |
|---|---|---|
| ■ Buy ENERGY STAR–qualified models<br>■ Review the FTC EnergyGuide label while shopping to compare the energy use and operating cost of models you are considering | ■ Optimize 4K TVs for energy efficiency<br>■ Ship TVs with ABC enabled | ■ Update test methods: include 4K and HDR content; revise standby testing for Internet-connected TVs |
| ■ Make sure automatic brightness control (ABC) is enabled | ■ Get ahead of HDR: develop consensus test clip, perform testing, and bring down energy use | ■ EPA: Reduce (and possibly eliminate) the additional power allowance for 4K/UHD TVs in the next revision of ENERGY STAR specifications<br>■ Utilities: Offer rebates for the most-efficient models on the market |
| ■ Avoid quick-start mode if you can | ■ Limit growth in standby power as new apps/features are added | ■ Consider mandatory standards at the state or federal level to remove the least-efficient models from the market |

## *Chapter 1*

# Ultra High-Definition: The Next Generation of Televisions

Following the introduction of high-definition television (HD TV), average television energy use rose dramatically, then leveled off and actually began to decline for the first time in many years. This came about as policymakers and utilities pursued very deliberate strategies to steadily nudge the television market in the direction of energy efficiency, while at the same time components with greater efficiency became available. Most notable was the incorporation of LED backlights, which provide significant energy savings compared to the older cold cathode fluorescent lamp (CCFL) technology.

Even though televisions became steadily bigger and brighter and offered higher resolution over the past decade, energy consumption continuously declined[1] as government agencies established standardized ways of measuring television energy use, required that this information be posted on all televisions sold in retail stores and on websites, highlighted the products that were more efficient than average with ENERGY STAR© labels, and established regulations in California that prohibited the sale of the least efficient technologies. Utilities in turn offered rebates for the most energy-saving models, helping persuade retailers to favorably market—and customers to preferentially purchase—energy-efficient televisions.

Today we face the confluence of three major market trends. First, manufacturers are increasingly deploying "smart" or Internet-connected capabilities in the majority of the television models they sell. Smart TVs allow the user to stream shows and movies directly over the Internet without an additional device such as a Roku or Apple TV box. This adds energy consumption when the television is streaming content and browsing the Internet. Even when the user thinks the television is switched off, it can consume energy to maintain network connectivity and to allow a quick boot-up when the television is switched on via a user-selectable "quick start" mode.

Second, manufacturers are migrating to so-called 4K models, also known as ultra high-definition televisions. These products offer higher resolution and more features than their standard-definition (SD) or high-definition (HD) counterparts. Specifically, 4K TVs offer up to four times the resolution of an HD TV. While this is a main attraction of these televisions, they offer other features that appear to have significant energy impacts, as we discuss later. In summary, UHD is a catch-all term the industry uses to describe the next generation of televisions that provide 4K resolution. To avoid confusion in the report between the terms UHD and 4K, we used the term 4K to describe the new high resolution televisions. If the 4K TV also had a feature such as high dynamic range (HDR), we refer to that television as 4K HDR.

Third, manufacturers and retailers are encouraging shoppers to upgrade to even larger screens to better showcase improved picture quality and image detail. The average television in U.S. homes in 2013 measured 34 inches diagonally; the average television sold today is 41 inches.[2] Large screens more dramatically display higher resolution and the improved color capabilities of today's advanced televisions. Also, improvements in the manufacturing process are allowing the creation of larger screens with a thinner profile and at a lower price than ever before.

Thanks to the confluence of these three trends, we now face the very real prospect that the vast majority of all new televisions larger than 36 inches will migrate to 4K smart television technology over the new few years. This threatens to push the energy use of televisions upward once again, not only when the products are displaying a picture (active mode), but also in various low-power modes where the user thinks the unit is off, but it is continuing to send and receive data via the Internet and is ready to start almost instantly.

To better understand the energy use of today's advanced televisions and how they compare with HD TVs, the Natural Resources Defense Council (NRDC) retained Ecos Research to test a cross-section of new 4K TV models and to review reported power levels from public databases. The research questions we sought to answer in this study included:

- Is there a wide range in the on-mode power levels among various 4K TV models of the same size?
- Do 4K TVs consume more power than similar-size HD TVs in active mode when displaying the same content?
- Is the average screen size of new televisions increasing?
- What impact does the automatic brightness control (ABC) feature have on measured On-mode power?
- What impact does the resolution or source of the incoming content have on On-mode power? Is there any difference when receiving HD versus 4K content? Is there a difference when receiving 4K content via streaming versus from a disc played on an upscaling Blu-ray player?
- What are the standby power and boot-up times for smart TVs when the quick-start feature is enabled or disabled?

- What is the incremental power use of a 4K TV with high-dynamic-range (HDR) capability when playing a movie encoded in HDR?
- What issues, if any, are identified regarding the official test methods used to perform the measurements?
- What is the national impact (annual total energy, tons of carbon pollution, etc.) of shifting from HD to 4K TVs?

## WHAT IS ULTRA HIGH-DEFINITION?

Many television consumers associate ultra high-definition (UHD) TVs with increased screen resolution (a higher number of pixels) relative to high-definition (HD) TVs. The acronym UHD has been used interchangeably with 4K, but UHD capability involves much more than picture resolution. Essentially, all UHD TVs will have 4K or greater resolution, but not all 4K TVs will deliver the full range of UHD capabilities. UHD is the convergence of multiple technology and feature trends, including increased resolution as well as also wider color gamut, HDR, higher frame rates, and improved audio capabilities (Figure 1).

The industry has created formal definitions for two UHD resolutions, 4K and 8K, but only 4K is being offered today so we focus our attention there. This resolution is also sometimes described as 2160p, which refers to its pixel height; it is 3,840 pixels wide by 2,160 pixels tall (8.29 megapixels). This gives a 4K TV four times as many pixels as full HD TV, which has a resolution of 1,920 by 1,080 (2.07 megapixels), as shown in Figure 2. In reality, a large portion of HD content viewed today is in 1080i or even 720p, so the potential jump in screen detail level is significant. 4K is likely to increase television energy use, because brighter LED backlights are required to push an equivalent amount of light through the smaller pixels and overcome the opacity of the additional pixel boundary lines.

While sources of true 4K content are currently limited, 4K TVs can play back HD and standard-definition (SD) signals by upscaling the resolution to 4K within the television. This artificially increases the resolution of HD or SD content to match the native resolution of the television and can increase perceived picture quality, depending on how well the upscaling is done. Availability of content provided in 4K resolution (or "native 4K") is increasing through streaming services such as Netflix, YouTube, and Amazon, which also have announced plans to support HDR content. Many new Blu-ray players also have the ability to upscale content to 4K before sending it to the television.[3] Game consoles with 4K support were expected to launch in late 2015 as well.

**Figure 1: Summary of the Various Elements Of UHD Capability**

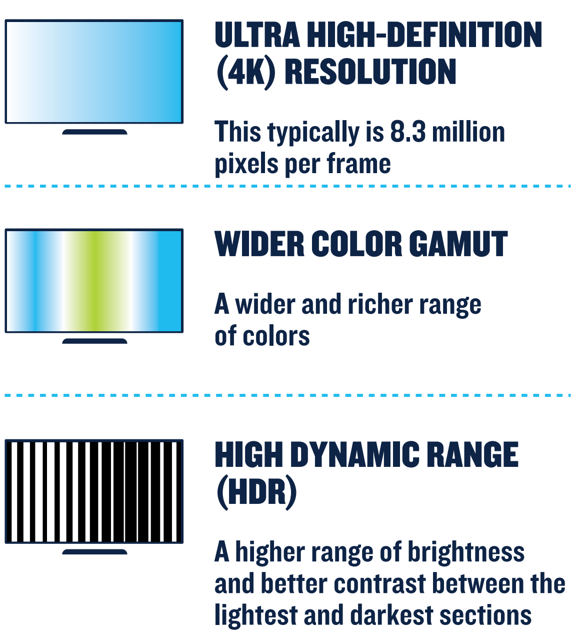
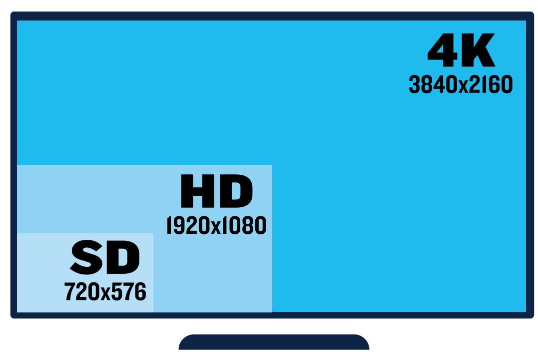



**Figure 2: 4K Resolution Compared to High Definition (HD) and Standard Definition (SD) in Pixels**




UHD enables other image enhancements as well. Each pixel in an HD TV has historically utilized eight bits of information for the red sub-pixel, eight bits for the green sub-pixel, and eight bits for the blue sub-pixel. This allows 256 different possible shades within each of those primary colors to make a range of different final colors at the whole-pixel level. With UHD, 10 or even 12 bits of information are now available for each colored sub-pixel, leading to dramatic increases in the number of final colors that each panel can display and in the resulting vividness or saturation of those colors. The general term for this capability is "wide color gamut," though each manufacturer markets its own implementation in a slightly different way, with terms such as "quantum dot" or "Triluminos." The energy impacts of wide color gamut capability are largely unknown.

In addition to drastically improving color reproduction, some UHD televisions support higher absolute luminance levels on portions of their screens through high dynamic range (HDR) technology. HDR maximizes the luminance difference between the brightest and darkest portions of screen image. Manufacturers are claiming 800 to 1,000 nits of peak luminance in HDR TVs, compared to about 300 to 450 nits in typical non-HDR TVs. (Nits are a unit of measure used to characterize screen brightness.) HDR implementation in the marketplace remains a work in progress. A television with HDR hardware capability may or may not yet have the updated firmware to support it. Moreover, even a television with onboard hardware and the necessary software support for HDR may deliver only a portion of the intended effect until furnished with content that has been HDR-encoded to tell the television when and how to display it to maximum effect.

HDR-encoded material can provide visually striking imagery that is more vivid and wide ranging in tonality than the original itself. Specially designed digital cameras and software capture multiple images per frame, each of which represents a portion of the range of visible light and dark tones. When these are combined, the final, composite image is contrast-enhanced to deliver extreme brightness in the highlights, natural mid tones, and deep shadow detail. Thus the top three frames of Figure 3 below become the one at lower left. By enriching with intensified colors, as is evident in the final frame, a television with both HDR and wide color gamut capabilities can render the full effect. The energy impacts of HDR have not been measured and disclosed prior to this research project but are largely associated with the additional brightness of the backlights.

Television shows and movies have historically utilized frame rates of 24 to 30 frames per second (fps), but UHD enables frame rates of 60 or even 120 fps. This will be noticeable primarily to viewers of sports and other rapidly moving images. UHD also supports new, more realistic audio formats. The potential energy impacts of these two changes are also largely unknown and were not part of this study. The combined effect of all of these changes sharply increases the amount of data delivered to televisions per minute. However, compression capabilities also continue to improve to allow some UHD capabilities to be delivered via streaming and a more complex set to be delivered through UHD Blu-ray discs scheduled to be released in early 2016. At that point, it may be possible to determine the cumulative energy impacts of the entire set of UHD features.

**Figure 3: HDR Image Processing**

## RESEARCH METHODOLOGY

Our research focused on 4K televisions and consisted of three main parts: (1) review and analysis of public databases managed by the California Energy Commission (CEC), the ENERGY STAR program, and the U.S. Department of Energy (DOE); (2) in-store testing by Ecos Research of selected 2014/2015 4K models; and (3) laboratory testing by Ecos Research of selected 2015 4K models.

Our analysis of the public databases focused on understanding the incremental energy consumption of 4K compared to HD in 2014 and 2015. In addition, to better understand market penetration of efficient televisions, we compared On-mode power values with the ENERGY STAR allowance levels set by the U.S. Environmental Protection Agency (EPA) in its voluntary labeling program.

While our 4K TV testing was intended to focus on 2015 models, manufacturers delayed the retail launch of many new models shown at the Consumer Electronics Show (CES) in January 2015. Therefore, some 2014 4K models are also included in this study. We selected televisions with a 55-inch screen size when possible, as this size represents the highest sales volume and one of the most competitive price points of fully featured UHD TVs available on the U.S. market today. Standardizing on a particular screen size makes it easier to compare test results as well.

To understand which variables have the greatest impact on power consumption, models selected for testing covered a broad range of brands, display technologies, and operating systems. In-store testing allowed us to gather data without having to purchase televisions, many of which were newly introduced at prices that sometimes exceeded $3,000. In the laboratory, using purchased televisions, we conducted dark-room testing with automatic brightness control (ABC) enabled for these models. ABC reduces On-mode energy consumption through a sensor that detects the room light level and adjusts the screen brightness accordingly. Given the difficulty of carefully controlling ambient lighting levels in a retail environment, we disabled ABC for in-store testing.

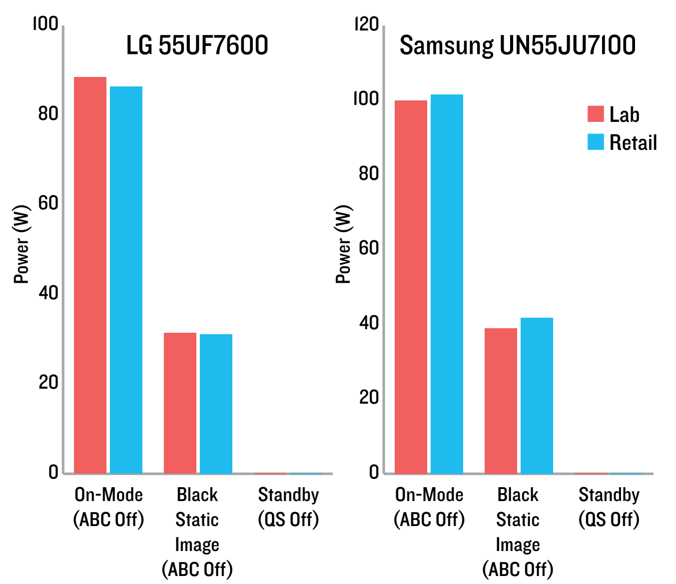
We analyzed 21 televisions in this study, roughly half in-store and half in the laboratory. While we tested only a fraction of the models available on the market, we believe we covered a sufficiently large cross-section of 55-inch televisions to answer the research questions we posed. Model specifications and features appear in the Test Results section of this report. We performed lab testing in accordance with the U.S. Department of Energy (DOE) test method and associated guidance documents (Appendix A: Test Methodology), utilizing the specified set of dynamic test clips and static test patterns contained on a Blu-ray disc from the International Electrotechnical Commission (IEC). Use of standardized content is important, as On-mode power can vary significantly, depending on the colors and average picture level (APL) of the images being displayed.

In addition to standardized tests defined by DOE, we performed supplementary testing with alternate content and resolutions and with certain features enabled or disabled. For example, if a smart TV ships with quick-start disabled, we left it this way for official testing and reporting purposes and then tested it with that feature enabled to understand what impact it has on start time and standby power use. We did this because some users may be dissatisfied by a television's slow start time and might then go into the settings and enable the quick-start (or similarly named) feature. Similarly, if a television ships with ABC enabled, we tested it that way and then a second time with ABC disabled. Since the IEC test disc and all currently available Blu-ray disc content still have a maximum native resolution of 1080p or HD, we utilized an OPPO brand Blu-ray player to upscale that content to 4K or streamed native 4K content from the Internet to characterize the incremental energy consumption over HD content.

For both lab and retail testing, a Chroma 61602 reference power source provided a stable AC waveform to the television. A Yokogawa WT-310 analyzer interfaced to a custom-designed LabVIEW control panel logged power measurements in real time. We configured test equipment and tolerances per the DOE/IEC standards with a sample rate of 250 milliseconds (ms) for all measurements. During lab-based ABC testing, we used a Konica T-10A meter to measure room illuminance. All test equipment (Appendix B: Test Equipment) held valid calibration certificates at the time of test.

We tested two different 4K models both in the lab and in the store to understand how the results would compare. There is good agreement in observed measurements for three separate tests performed, as shown in Figure 4. The next section of this report details results and observations for all televisions tested by Ecos Research.

**Figure 4: Lab vs. Retail Test Power Measurement Results For Two TVs**



# *Chapter 2*
# Using Data to Understand 4K TV Energy Use

Our study includes both dataset analysis and the testing of models in stores and in the lab. This chapter details our review and analysis of public databases managed by the California Energy Commission (CEC), ENERGY STAR program, and U.S. Department of Energy (DOE). We focused on understanding the reported incremental energy consumption of 4K compared with HD in 2014 and 2015. To better understand the overall market response, we analyzed model-specific reported values for On-mode power in comparison to ENERGY STAR allowance levels. We also partnered with the consulting firm Energy Solutions and its client, the Northwest Energy Efficiency Alliance (NEEA), to determine and compare trends in HD and 4K technology. For this analysis, we used Pacific Northwest sales data provided by the market research firm NPD. We assumed data from this region is sufficiently representative of television sales for the country as a whole. In order to estimate national sales trends, we extrapolated the NPD regional sales data to the national market based on population count. We projected 2015 sales based on year-to-year and monthly sales trends leading up to 2015.

## SCREEN SIZE ANALYSIS

As mentioned previously, larger screen sizes have become increasingly popular and are being heavily promoted by retailers. By analyzing the NPD data, we determined that nearly a third of all new television sales in the Northwest are for screen sizes 50 inches and greater. As shown in Figure 5, 50- to 60-inch televisions now have the highest market share of any television size and outsell the 40- to 46-inch televisions that previously occupied the sweet spot for big-screen televisions. In terms of new sales, 55-inch is increasingly becoming the new 42-inch.

Figure 6 shows that within each range of large-screen sizes, 4K televisions have rapidly gained market share over the past two years. For example, as of June 2015, 4K TV sales represent about 65 percent of television sales greater than 60 inches. For televisions between 50 and 60 inches diagonal, 4K TV sales represent about 40 percent of the total.

**Figure 5: Sales by Screen Size**

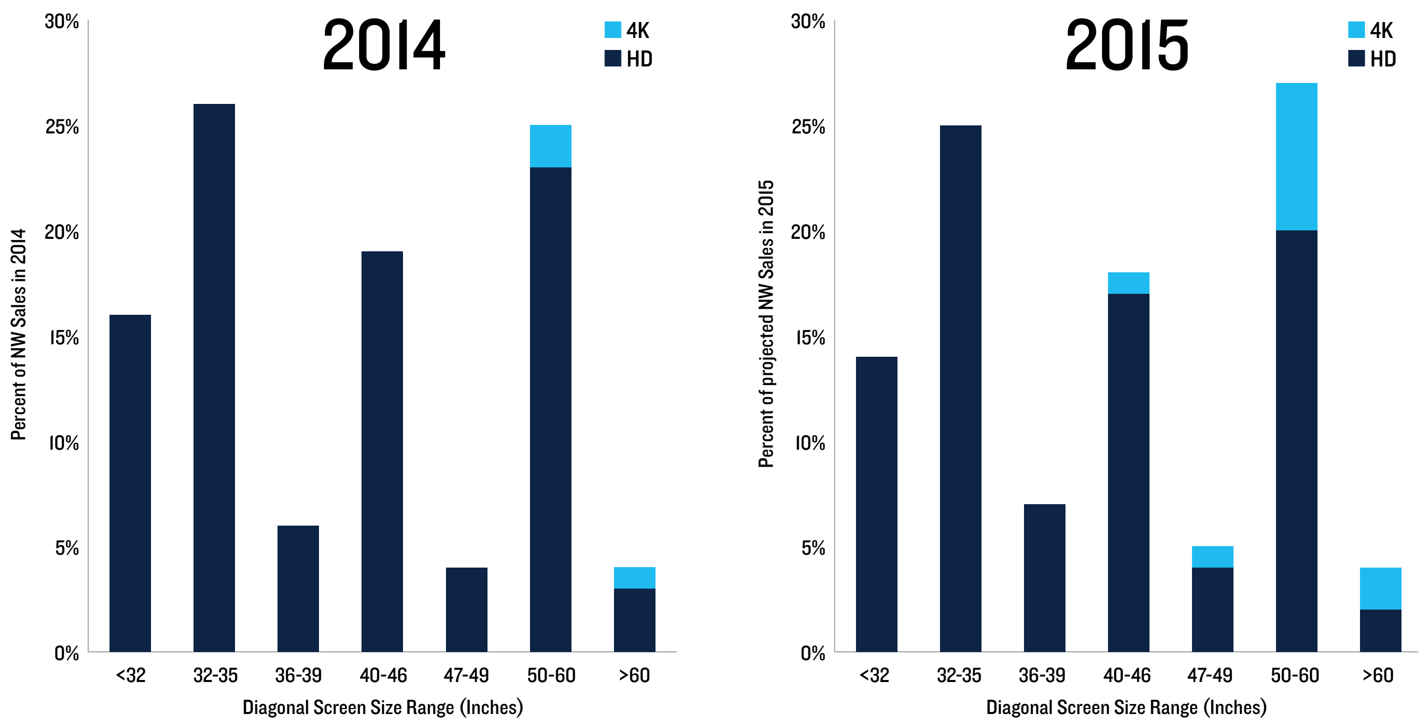
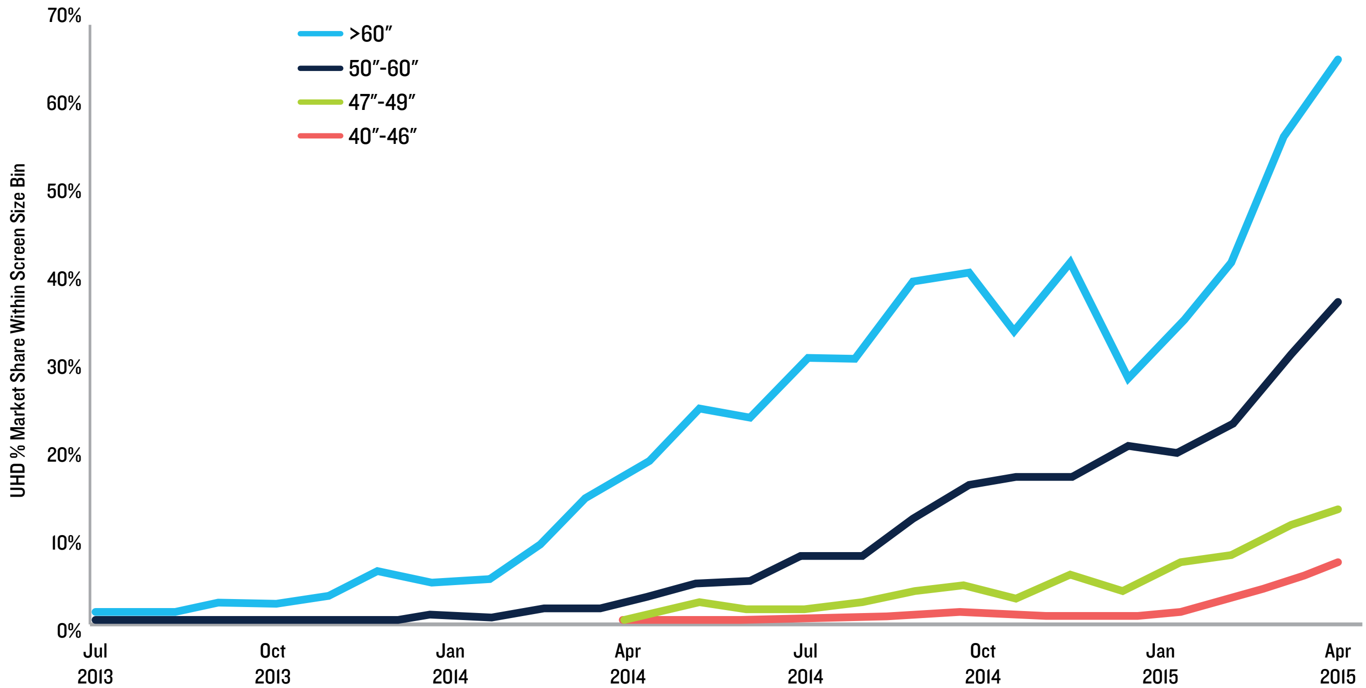


**Figure 6: Market Share Trends For Various Screen Sizes**




## 4K TV ON-MODE POWER

Our public dataset analysis assessed how 4K TV On-mode power compared with the maximum allowable power curves from the EPA's ENERGY STAR labeling program. The EPA aims to have its specifications represent approximately the top 25 percent of the market in terms of energy use when new ENERGY STAR specifications go into effect. ENERGY STAR Version 6.1, the current iteration, took effect in June 2013; Version 7 goes into full effect on October 30, 2015.

Version 7's requirements provide a 50 percent additional On-mode power allowance for models with a native vertical resolution greater than or equal to 2,160 lines, which includes 4K TVs. ENERGY STAR names this high-resolution on-mode power allowance PHR. Graphs contained in this report label this 50 percent allowance as ENERGY STAR 7.0 HR, as shown in Figure 7.

The combined CEC, EPA, and DOE datasets from June 2015, with duplicate entries removed when possible, contain 151 4K models from 2014 and 189 4K models from 2015. A detailed look at the reported On-mode power levels of 2014 and 2015 4K models (Figure 7) reveals that above 60 inches, television power use of the least efficient models rises dramatically in both model years.

Focusing on televisions with a 50- to 60-inch screen size, we plotted the On-mode power data from the databases (Figure 7) and our measured values, shown as diamonds in Figure 8, alongside the maximum allowable power curves from the ENERGY STAR labeling program. The TV models selected for lab testing represent a wide range of typical On-mode power use relative to equivalent-screen-size 4K models found in public datasets. Some models we tested consume more than 2.5 times as much power as others with the same screen size, while some 55-inch 4K TVs use less power than 50-inch models, even though they have roughly 20 percent more screen area.

Many 4K models already meet the 4K qualifying level for ENERGY STAR Version 7, several months before its effective date. In fact, a few 4K models on the market already meet the ENERGY STAR Version 7 level for non-4K models, which is considerably more stringent than the maximum allowable levels for 4K models.

## COMPARISON OF HD TO 4K TV ENERGY CONSUMPTION

We used model-specific Pacific Northwest market data to calculate the average difference reported in annual energy consumption (AEC) between HD and 4K TVs. First we

**Figure 7: Reported Power Use by Screen Size (HR indicates the high-resolution allowance)**

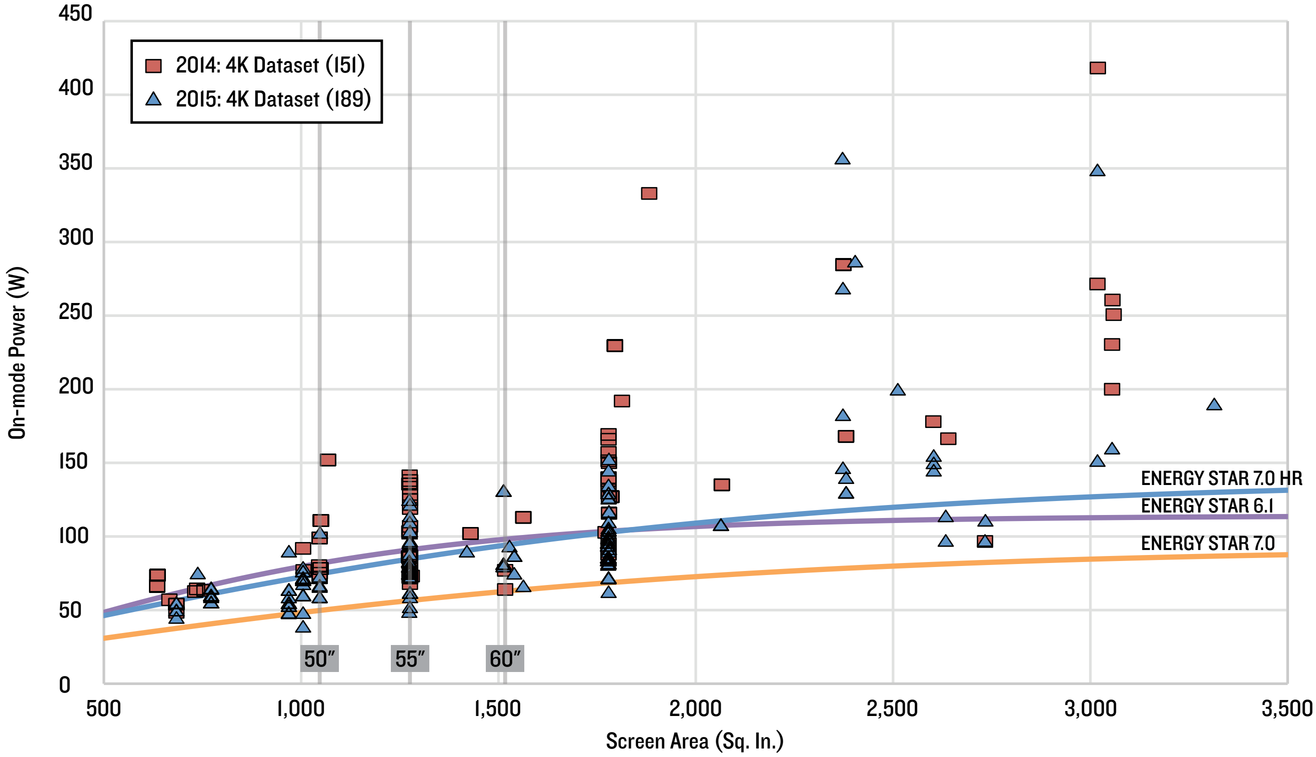
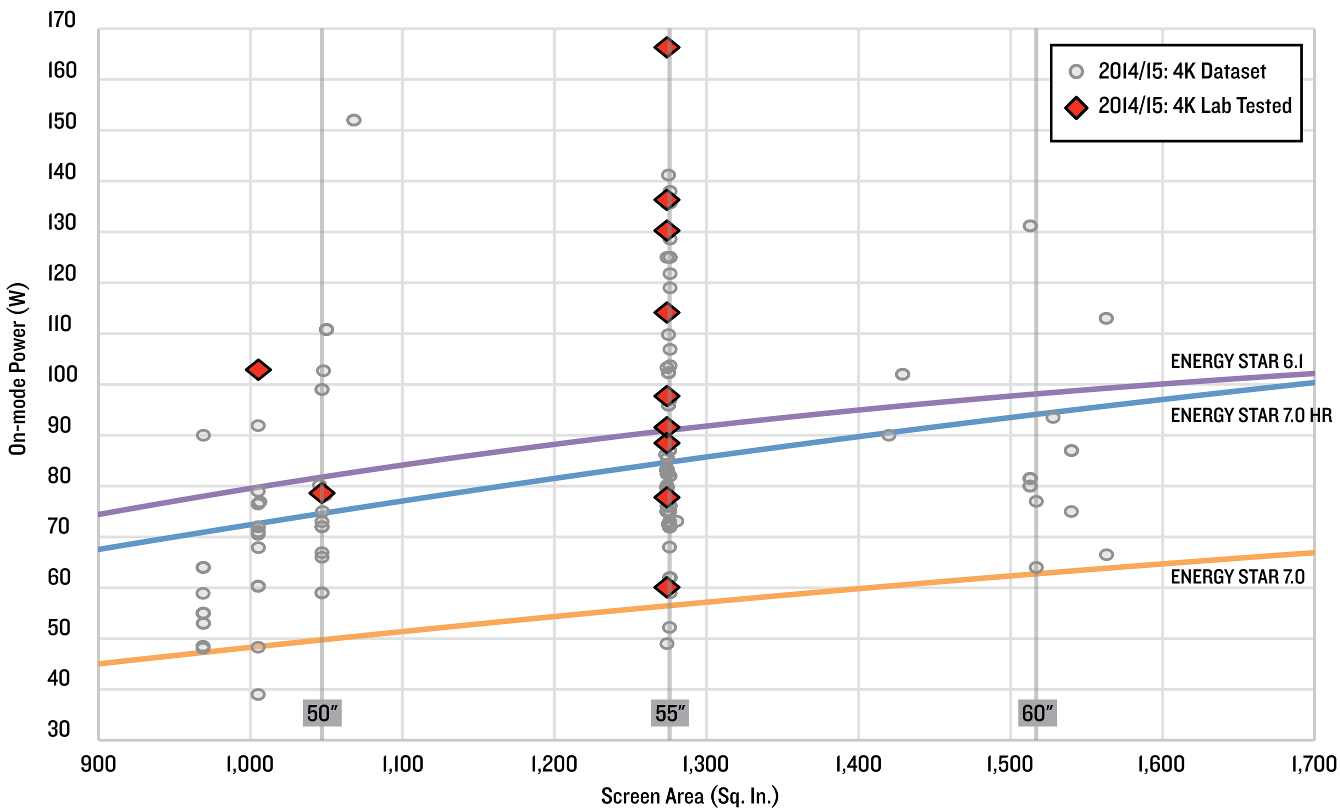



**Figure 8: Lab-tested 4K TVs' Power Use and Reported Use from Databases**




Red diamonds represent models tested by Ecos. Oother data points are from public databases and reflect manufacturers' reported values.

**Figure 9: Sales-weighted Comparison of 4K vs. HD TV Average Annual Energy Consumption for Projected 2015 Sales**

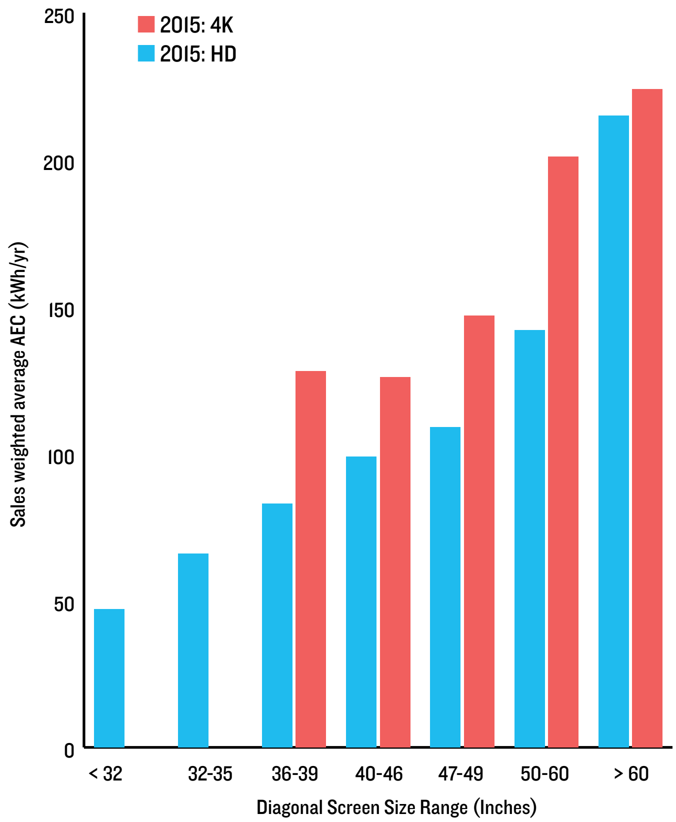
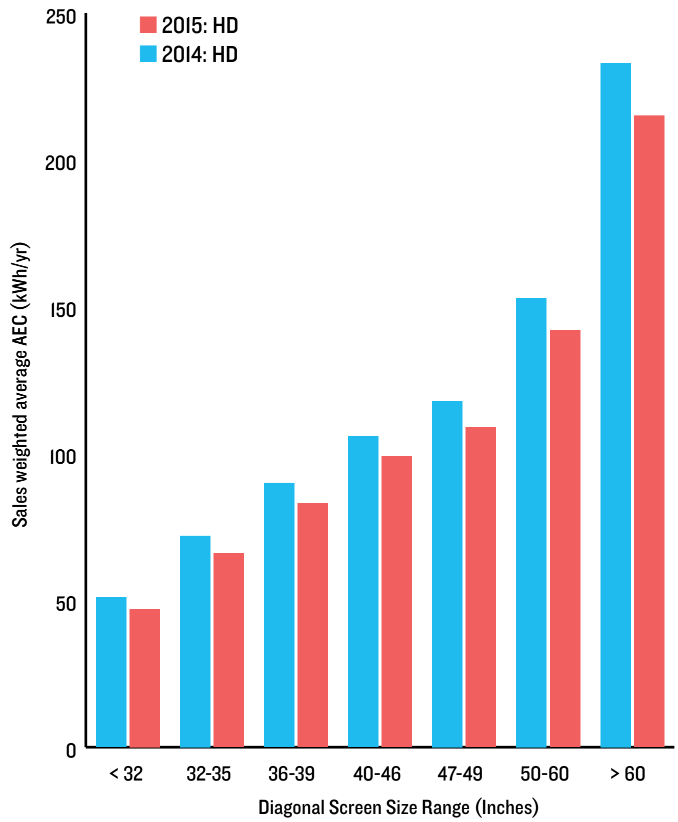



**Figure 10: HD Year-to-Year Average Annual Energy Consumption**




calculated average AEC values across seven screen-size ranges or bins (Figure 9) based on actual sales for the first half of 2015.[4] By then weighting the average AEC values by projected 2015 sales of 4K TVs in each size range (zero sales for TVs less than 36 inches), we determined that 2015 4K TVs consume 33 percent more energy annually than 2015 HD TVs.

A similar calculation for 2014, using 2014 actual sales and associated average AEC, yields a 26 percent penalty for 4K. Therefore, we conclude that today's average 4K TV uses approximately 30 percent more energy than an equal-size HD TV, based on reported test results using the HD IEC test clip.[5] Additional details of the methodology used for this analysis, including Pacific Northwest sales information and screen sizes, is included in Appendix C: National Energy Impact Methodology.

## YEAR-TO-YEAR IMPROVEMENT IN AVERAGE ANNUAL ENERGY CONSUMPTION

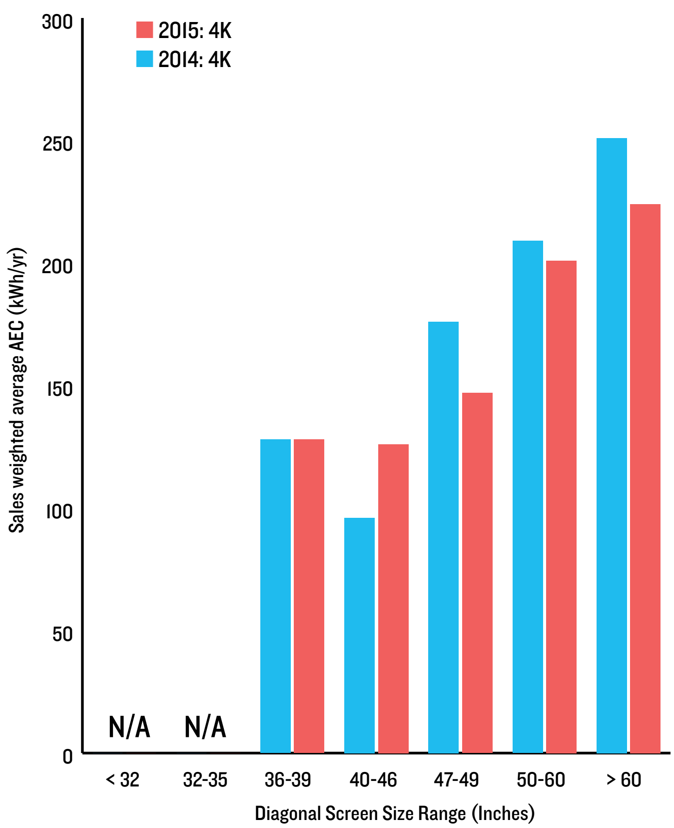
Year-to-year (YTY) efficiency improvements from 2014 to 2015 resulted in an 8 percent decline in HD TV annual energy use and a 4 percent decline for 4K TV. Using the same dataset as in the previous section, we computed overall YTY improvement by first calculating the 2014 to 2015 percentage improvement in AEC independently for HD (Figure 10) and 4K (Figure 11), across seven screen size ranges (also known as bins). We then computed the resulting YTY AEC improvements by weighting the HD improvement percentages by projected 2015 HD sales percentages per bin, and weighting the 4K improvement percentages by the projected 2015 4K sales percentages per bin.

## NATIONAL ENERGY IMPACT OF SHIFT TO 4K TV

Given the lack of a recent national energy consumption analysis for installed televisions, we put the potential national impact of 4K TVs into perspective by simply asking the question "How much additional energy would be required to power the nation's 300 million[6] installed TVs if they were 4K compared to HD?"

For the base case, Scenario A, we replace all 300 million televisions with the average HD model in use today. In Scenario B, we replace all televisions of at least 36 inches with the average 4K model in 2015 and leave televisions smaller than 36 inches as the average 2015 HD. We recognize that not all of today's installed televisions are HD, so both the base case and Scenario B are hypothetical.

**Figure 11: 4K Year-to-Year Average Annual Energy Consumption**




Without further gains in television energy efficiency, transitioning from all HD (Scenario A) to a mix of HD and 4K TVs (Scenario B) would result in an additional 8 TWh of annual energy consumption and 5 million more tons of $CO_2$ emissions each year (Table 1). This translates to an additional $1 billion spent on powering our televisions every year and requires the energy output of 2.5 average (500 MW) coal-fired power plants. Stated another way, the additional electricity consumption caused by a shift to 4K TVs is more than three times the amount of electricity used each year by all the homes in San Francisco.[7]

In performing these calculations we assumed a national electricity cost of 12.5 cents per kilowatt-hour.[8]

Note that these estimates do not include the additional energy impacts of other technologies just beginning to show up in UHD TVs, including HDR, wide color gamut, and higher frame rates, nor the continuing preference for larger screen sizes over time. Including all of these impacts could cause television energy use to roughly double, depending on how widely HDR content proliferates.

**Table 1: Potential National Energy Impact Scenario[9]**

| | Scenario A<br>All installed TVs replaced with weighted average HD model sold in first half of 2015 | Scenario B<br>All large TVs (>35” diagonal) in Scenario A replaced with 4K models* | National Impact<br>Difference between Scenarios A and B |
|---|---|---|---|
| Installed TVs (millions) | 300 | 300 | - |
| Average screen size (inches) | 41 | 41 | - |
| Average AEC (kWh/yr) | 99 | 125 | 26 |
| National energy consumption (TWh/yr)** | 29.5 | 37.5 | 8.0 |
| Number of average (500 MW) coal power plants needed** | 10.0 | 12.5 | 2.5 |
| Metric tons of $CO_2$ emissions (million) | 16.5 | 21 | 4.5 |
| Cost of electricity ($ billion) | 4 | 5 | 1 |
| Percent of national residential electricity consumption | 2% | 3% | 1% |

*4K analysis does not include incremental energy consumption of HDR. ** Rounded to nearest 0.5.

*Chapter 3*

# Using Store and Lab Testing to Show 4K TV Energy Use

We performed all in-store and laboratory testing between April and July 2015. Table 2 and Table 3 provide specifications for the 11 models purchased for laboratory testing and the 10 models selected for retail testing. Empty fields indicate that the information was not publicly available from the manufacturer. *See Appendix D: Detailed Data Tables for a consolidated list of test results.*

Plotting On-mode power for lab-tested televisions (Figure 12) shows a nearly 2:1 difference in power use of ABC-enabled 4K TVs of the same size. For example, the Samsung 7100 model uses roughly half the power that the Panasonic 850U TV does with ABC enabled. The spread in On-mode power levels for 55-inch televisions is even more dramatic when comparing the most efficient models with those that did not ship with ABC enabled, such as the Vizio models. Note that Vizio's TVs have much lower On-mode power levels when tested with ABC enabled. It should be pointed out that since Vizio ships its televisions with this feature disabled, it is tested this way and as such has a much higher reported on-mode power level (for more information refer to Figure 14 on page 21).

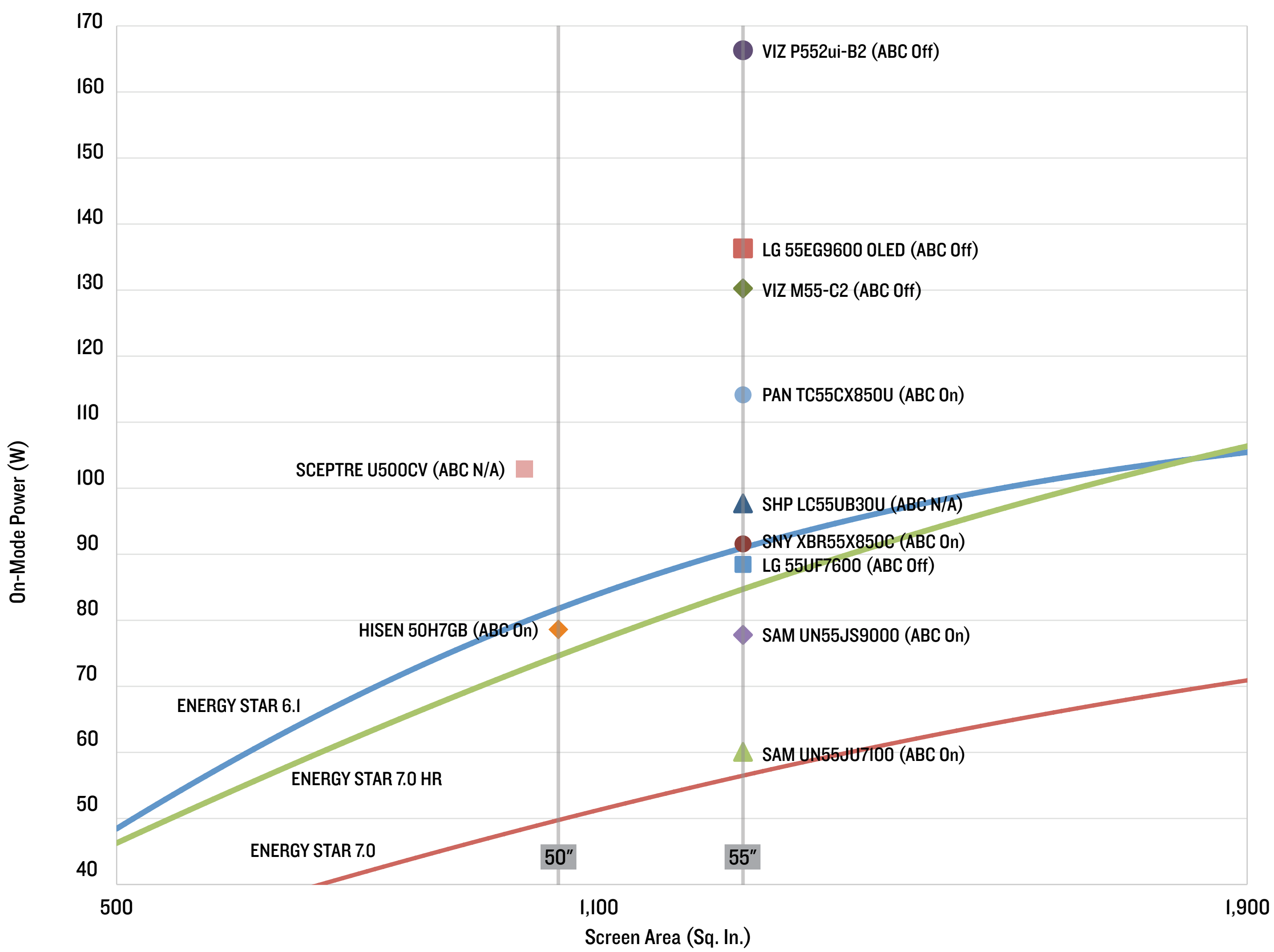
The LG 55EG9600 was the only television we tested that contained organic light emitting diode (OLED) technology. While this technology has been very popular in cell phones and tablets, in part for its ability to extend battery life through higher energy efficiency, early-generation OLED TVs do not yet appear to be more energy efficient than their LCD counterparts. However, manufacturer-reported energy consumption values for LG's new 9500 series OLEDs are about 29 percent lower than for its 9600 series OLEDs released earlier in 2015. We anticipate OLED TV energy efficiency may continue to improve as the technology matures.

**Table 2: Specifications of TVs Tested by Ecos in the Lab and Results of On-mode Power Testing**

| MFG | Hisense | LG | LG | Panasonic | Samsung | Samsung | Sceptre | Sharp | Sony | Vizio | Vizio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Model | 50H7GB | 55EG9600 | 55UF7600 | TC-55CX850U | UN55JS9000 | UN55JU7100 | U508CV-UMK | LC55UB30U | XBR55X850C | M55-C2 | P552ui-B2 |
| Year | 2015 | 2015 | 2015 | 2015 | 2015 | 2015 | 2015 | 2015 | 2015 | 2015 | 2014 |
| Screen Size | 49.5 | 54.6 | 54.6 | 54.6 | 54.6 | 54.6 | 48.5 | 54.6 | 54.6 | 55 | 54.64 |
| Vertical Resolution | 2160 | 2160 | 2160 | 2160 | 2160 | 2160 | 2160 | 2160 | 2160 | 2160 | 2160 |
| Price (Amazon) | $598 | $5,499 | $1,399 | $2,999 | $2,497 | $1,597 | $520 | $999 | $1,599 | $999 | $999 |
| Backlight | LED Edge Lit | N/A | LED Edge Lit | LED Full Array | LED Edge Lit | LED Edge Lit | LED Edge Lit | LED Edge Lit | LED Edge Lit | LED Full Array | LED F ull Array |
| Panel Technology | ------- | OLED | IPS | ------- | Quantum Dot | ------- | ------- | ------- | Quantum Dot | ------- | IPS |
| Processor | ------- | Quad-core | Quad-core | Quad-core | Octa-core | Quad-core | ------- | Quad-core | ------- | Dual-core CPU | Dual-core CPU |
| OS | Opera | webOS | webOS | Firefox OS | Tizen | Tizen | Proprietary | SmartCentral | Android TV | Proprietary | Proprietary |
| Voice Interaction | No | Yes | Yes | Yes | Yes | Yes | No | No | Yes | No | No |
| ABC Sensor | Yes | Yes | Yes | Yes | Yes | Yes | No | No | Yes | Yes | Yes |
| Quick-start Option | No | No | No | No | Yes | Yes | No | Yes | No | No | No |
| On-Mode Power (ABC On) Measured Value (watts) | 78.62 | 108.67 | 48.26 | 114.14 | 77.79 | 60.08 | N/A | N/A | 91.57 | 67.66 | 107.42 |
| On-Mode Power (ABC Off) Measured Value (watts) | 94.64 | 136.32 | 88.47 | 152.00 | 125.00 | 99.94 | 97.12 | 97.71 | 107.57 | 130.25 | 166.32 |

| Table 3: Specifications of TVs Tested by Ecos in Retail Stores and Results of On-mode Power Testing | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **MFG** | **LG** | **LG** | **LG** | **Samsung** | **Samsung** | **Samsung** | **Samsung** | **Sharp** | **Sony** | **Sony** |
| Model | 49UB8500 | 55EC9300 | 55UF7600 | UN55JS8500 | UN55JU6500 | UN55JU7100 | UN65JS9500 | LC60UD27 | XBR55X800B | XBR65X900B |
| Year | 2014 | 2014 | 2015 | 2015 | 2015 | 2015 | 2015 | 2014 | 2014 | 2014 |
| Screen Size | 48.5 | 54.6 | 54.6 | 54.6 | 54.6 | 54.6 | 64.5 | 60.09 | 54.6 | 64.5 |
| Vertical Resolution | 2160 | 1080 | 2160 | 2160 | 2160 | 2160 | 2160 | 2160 | 2160 | 2160 |
| Price (Amazon) | $1,995 | $2,499 | $1,399 | $1,997 | $1,098 | $1,597 | $4,997 | $1,499 | $1,298 | $3,798 |
| Backlight | LED Edge Lit | OLED | LED Edge Lit | LED Edge Lit | LED Edge Lit | LED Edge Lit | LED Full Array | LED Edge Lit | LED Edge Lit | LED Edge Lit |
| Panel Technology | IPS | 4 Color Pixel | IPS | Quantum Dot | ------- | ------- | Quantum Dot | SPECTROS | ------- | Quantum Dot |
| Processor | Dual-core | ------- | Quad-core | Quad-core | Quad-core | Quad-core | Octa-core | Dual Core | ------- | ------- |
| OS | webOS | webOS | webOS | Tizen | Tizen | Tizen | Tizen | Proprietary | Proprietary | Proprietary |
| Voice Interaction | Yes | Yes | Yes | Yes | No | Yes | Yes | ------- | ------- | Yes |
| ABC Sensor | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Quick-start Option | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| On-Mode Power (ABC On) Measured Value (watts) | Not Tested | Not Tested | Not Tested | Not Tested | Not Tested | Not Tested | Not Tested | Not Tested | Not Tested | Not Tested |
| On-Mode Power (ABC Off) Measured Value (watts) | 92.51 | 91.68 | 86.35 | 100.37 | 89.04 | 101.55 | 145.26 | 169.51 | 83.04 | 181.77 |

**Figure 12: 4K TV On-mode Power Levels for Lab-tested Models**



In Figure 13, we display the test results in terms of their annual energy consumption (AEC) in kWh/yr for the televisions that we tested in the laboratory. AEC was calculated using the DOE-specified daily duty cycle of five hours in On-mode and 19 hours in standby mode. The AEC levels of televisions tested ranged from a low of 110 kWh/yr to a high of just over 300 kWh/yr. At a national average electricity rate of 12.98 cents per kWh,[10] this 190 kWh/yr incremental energy use between the most and least energy-consuming 55-inch models translates to an extra $246 in utility bills per television over the 10-year life of a new unit.

## THE IMPACT OF AUTOMATIC BRIGHTNESS CONTROL

Televisions with the automatic brightness control (ABC) feature enabled can monitor the level of light entering the front of the television and automatically adjust picture brightness to provide the best viewing experience under those lighting conditions. ABC saves a significant amount of energy when consumers watch televisions in dimly lit rooms, as is generally recommended for optimum picture quality.

Per our understanding of the U.S. Department of Energy (DOE) test method, we tested televisions with ABC on if they ship with ABC enabled by default and do not offer the user the ability to turn off the feature during the initial setup. We tested with ABC off if the television ships with ABC disabled or provides the user a choice to disable it during the initial setup. Figure 14 shows a screen shot of one of the LG TV models we tested where the "Auto-Energy Savings" (their term for ABC) feature was shipped enabled and an icon is provided that allows the user to change this setting. As the user could disable the auto energy savings feature during the initial set up, we tested the LG model with this feature off.

For testing performed with ABC on, power measurements were made at four room illuminance levels—3, 12, 35, and 100 lux, in accordance with the DOE test procedure—and the reported On-mode power is the average of these four measured power values. For comparison, 100 lux is representative of ambient light levels on a very, overcast day, while 1 lux represents twilight.[11] Although users can operate televisions in ambient lighting conditions higher than 100 lux, such as in a brightly sunlit room, DOE testing does not subject ABC systems to such conditions.

Generally, manufacturers of televisions that offer ABC enable it by default to help them qualify for ENERGY STAR. They also provide users an option, deep within their menu structure, to disable it later if they choose. Vizio offers the ABC feature but disables it by default; the lower-cost models we tested from Sharp and Sceptre lack an ABC feature. It is not known why Vizio chose to ship their televisions with ABC off, as their ABC feature—when enabled—could dramatically reduce a TV's On-mode power use.

**Figure 13: Spread of 4K TV Annual Energy Use (kWh/yr) of Lab-tested Models**

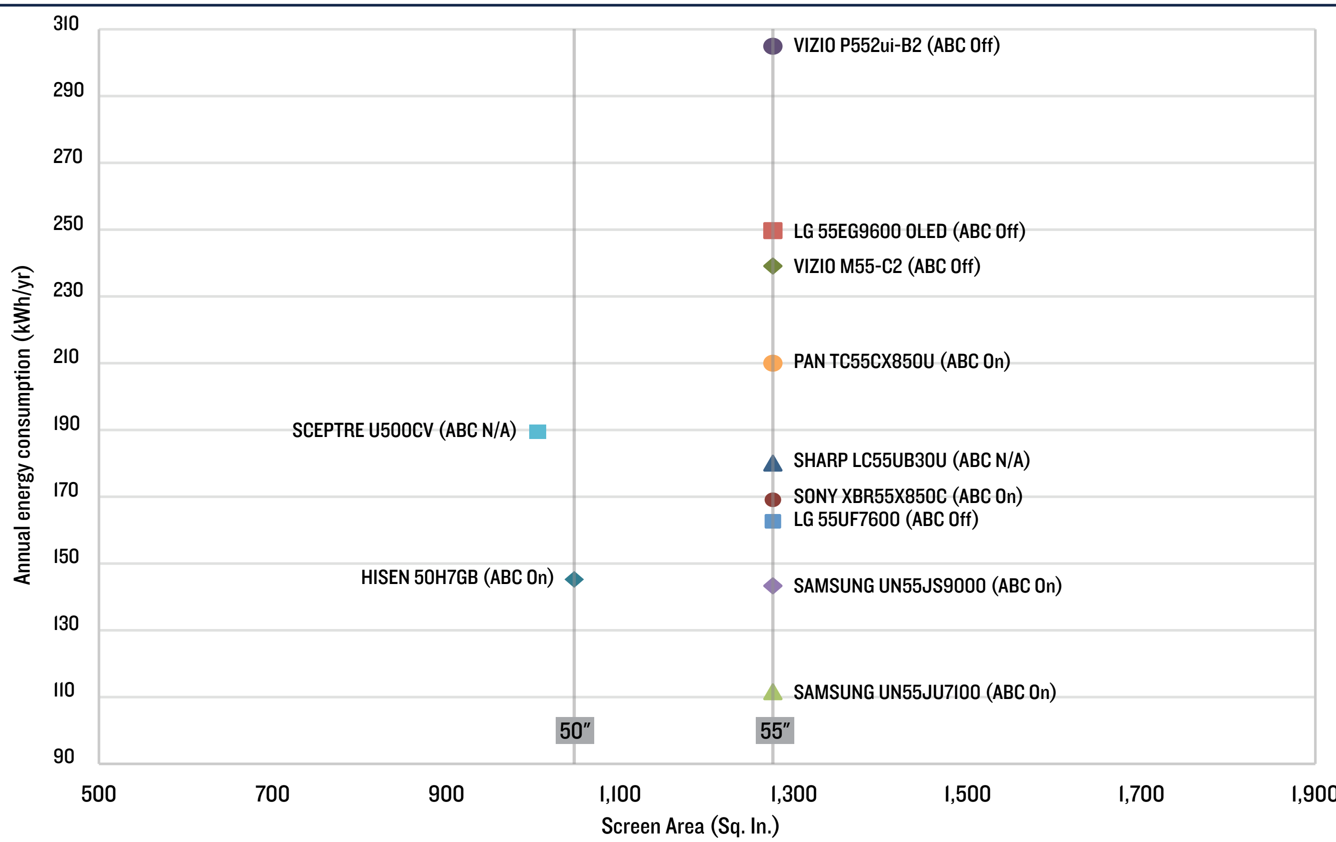
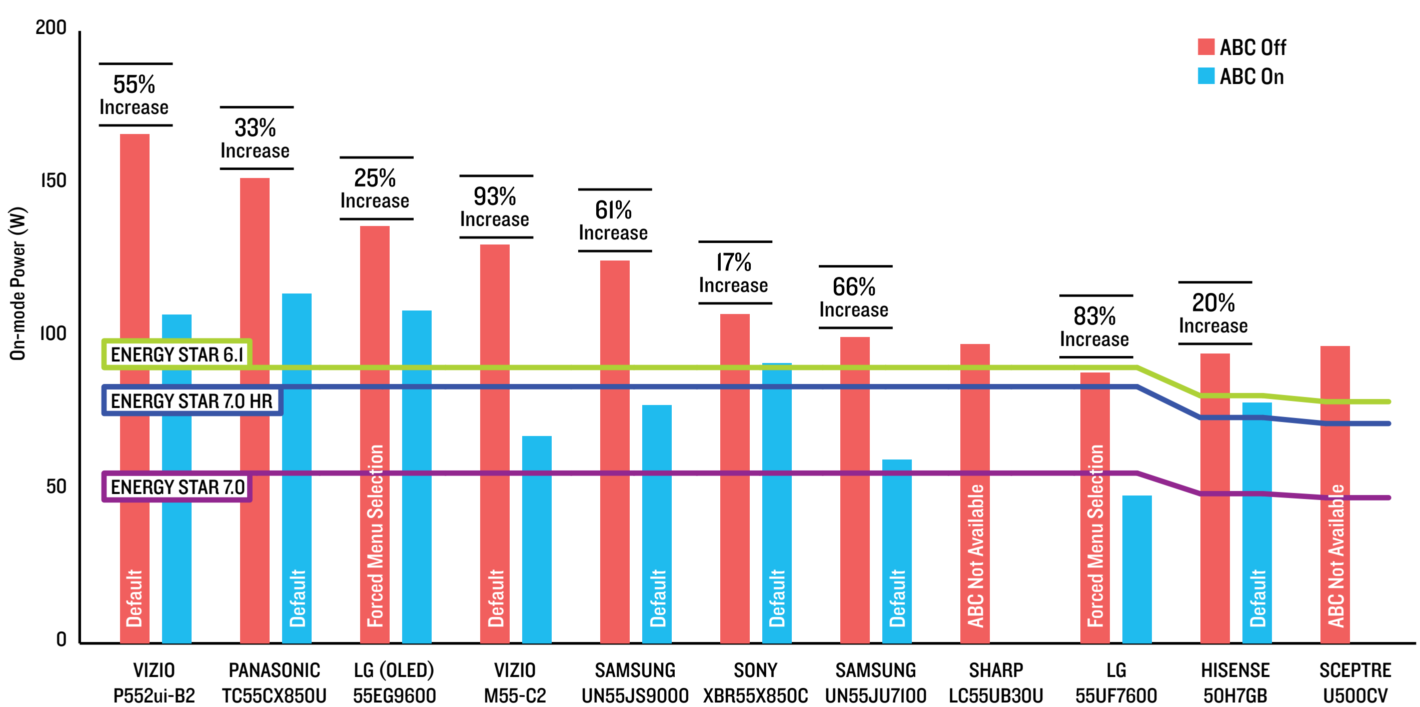


**Figure 14: LG's Forced Menu Includes Automatic Brightness Control Settings Described as Auto-Energy Savings**


In our laboratory testing of 55-inch models, we found the 4K TVs used an average of 50 percent more power with ABC off than with it on. The range varied from 17 percent to 93 percent. Per our understanding of the DOE test method, the value that would be reported is identified by the bar containing white text in Figure 15. The Vizio and LG models showed the greatest difference in On-mode power levels between ABC on and ABC off.

A closer look at the Vizio and LG values shows that a single change in how companies design their initial setup screens and default ABC mode can dramatically reduce reported On-mode power use. In some cases, this change alone would result in their qualification for the latest version of ENERGY STAR. In addition, manufacturers would be able to report much more competitive values for energy use and annual operating cost on the yellow EnergyGuide label and possibly qualify for rebates from local utilities.

**Figure 15: Comparison of 4K On-mode Power Use with ABC On and Off**



Given the substantial impact ABC has on the power use of the televisions we tested, we looked at how the European Union (EU) treats this power-saving feature. The European Commission's Eco-design requirements differ from the U.S. test method in that manufacturers test televisions with ABC turned off and must limit the credit taken for ABC to 5 percent of the annual On-mode energy consumption with ABC off. Below is an excerpt from EU regulation No. 1062/201.[12]

For the purposes of calculating the Energy Efficiency Index and the annual on-mode energy consumption...the On-mode power consumption as established according to the procedure set out in Annex VII is reduced by 5 percent if the following conditions are fulfilled when the television is placed on the market:

- The luminance of the television in the home-mode or the on-mode condition as set by the supplier is automatically reduced between an ambient light intensity of at least 20 lux and 0 lux;
- The automatic brightness control is activated in the home-mode condition or the on-mode condition of the television as set by the supplier.

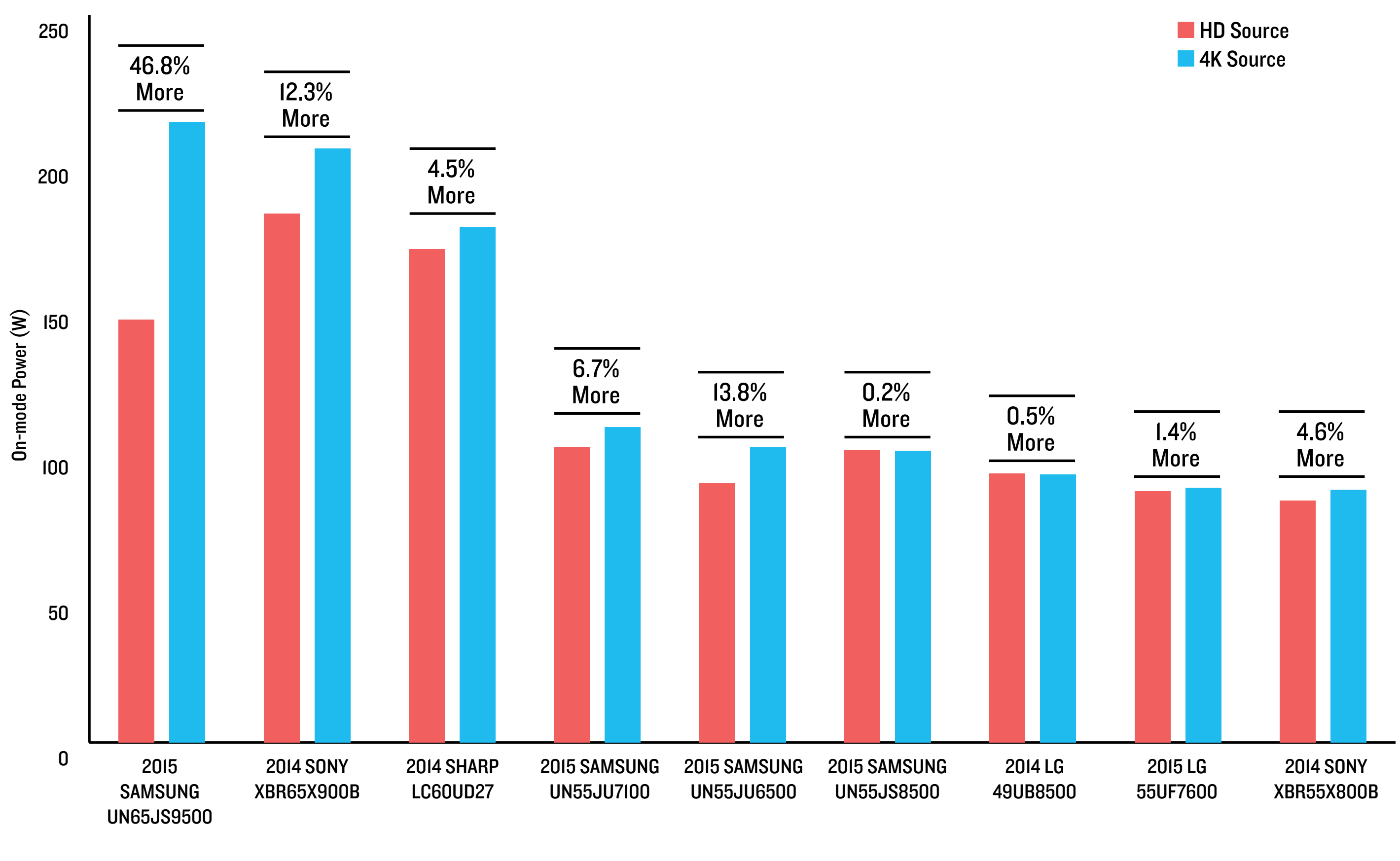
One must keep this rule in mind when comparing reported On-mode power levels in the United States with those reported in the EU. Additional testing would be useful to determine if the roughly 50 percent average impact of ABC observed during our testing is representative across all screen sizes or if the impact is different for smaller or larger televisions.

## HD AND 4K CONTENT FROM LOCAL AND STREAMED MEDIA

The DOE method uses the IEC Blu-ray disc broadcast content for measuring television On-mode power. Since 1080p (HD) resolution is the default format for the IEC optical disc, and since there are no DOE-specific tests for 4K, we needed to develop a test to determine whether 4K TVs use more power than reported when they receive 4K content in real-world use.

We determined differences in power by testing the IEC test clip on an OPPO Blu-ray player with two different configurations. In the first configuration, we sent a 1080i signal from the Blu-ray television (typical of what is distributed via cable or satellite HD programming) to the TV, which then upscaled it to 4K. In the second, the signal was upscaled by the OPPO player to 4K before it was sent to the television. We performed this testing in retail locations on 2014 and 2015 models, with ABC disabled.

**Figure 16: Comparison of On-mode Power Levels When Viewing 4K and HD Content**



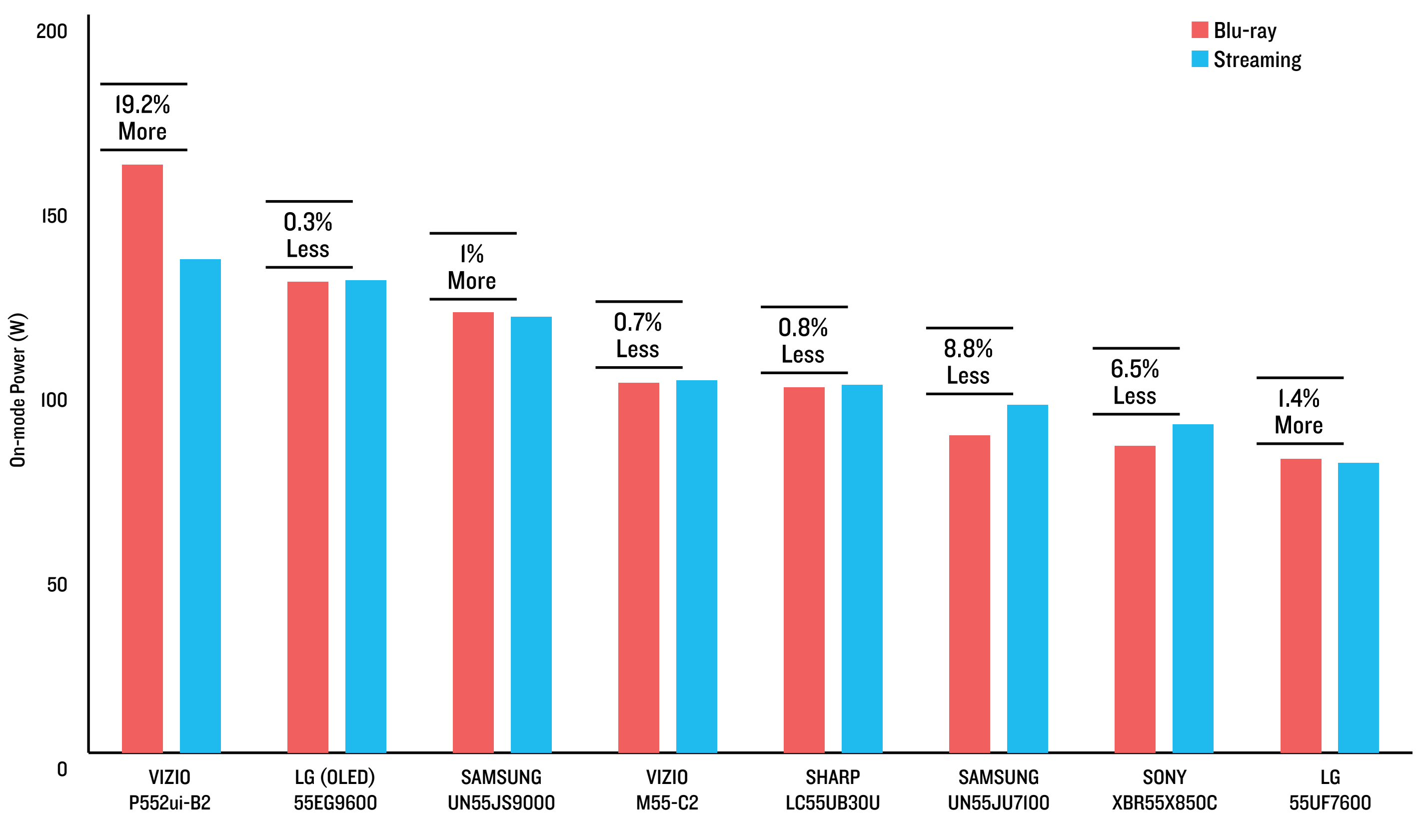
Our tested 4K TVs used 10 percent more power, on average, when displaying native 4K content compared with HD content (Figure 16).[13] One particular outlier is the Samsung 65JS9500, which showed a 46.8 percent increase in On-mode power when displaying 4K content. Omitting this model, we found that the remaining televisions use 5.5 percent more power, on average, when displaying native 4K content compared with HD. Further investigation might be warranted to better understand why the Samsung model yielded such a large difference in On-mode power levels for HD versus 4K content. (Note: this television was one of the few we tested that were HDR-capable.)

We then performed similar testing with streamed media. Although native 4K content has been minimally available to date, its availability is increasing via streaming services such as Netflix, Amazon, and YouTube. The majority of televisions sold today can access the Internet wirelessly or via Ethernet connection without the use of external devices such as Roku, Google Chromecast, or Apple TV. The term "smart TV" generally refers to a television with streaming functionality, but it can entail many other capabilities as well.

Our next research goal was to assess smart TVs' On-mode power usage when streaming and when receiving content from a disc. We did this by testing power levels when the televisions were streaming a 4K movie from Netflix, and again when they were playing the same content from a 1080p Blu-ray disc that had been upscaled by the Blu-ray player to 4K before going to the television. To perform this comparison, we used a 10.5-minute clip from the movie *Crouching Tiger, Hidden Dragon* that contained a wide range of dark, light, and intermediate-brightness images with both slow and rapid movement. Again, we performed all of these tests with ABC disabled because the light from the screen reflecting onto the walls of the testing lab and then back onto the ABC sensor introduced additional variability that could mask the differences we were seeking to measure.

Results (Figure 17) indicate that streaming 4K video through smart TV apps does not generally increase energy use relative to displaying 4K content from a local source. On average, the difference in the measured On-mode power was relatively small; the exception was the Vizio model, an outlier that used 19.2 percent more power when displaying a movie from a disc than when streaming.

**Figure 17: On-mode Power When Viewing 4K Content from Blu-ray vs. Streaming**



## IMPACT OF HDR CONTENT ON ON-MODE POWER USE

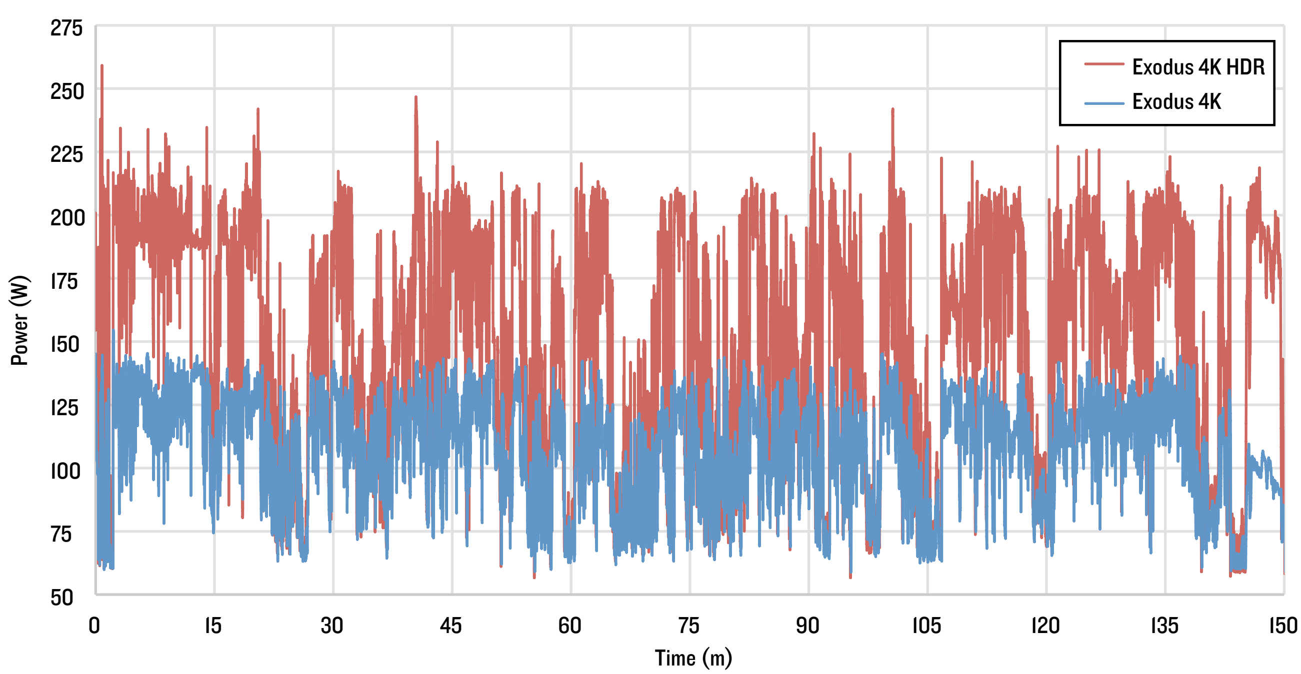
High dynamic range (HDR) has only recently debuted in the television market. Debates continue within the industry over the amount of maximum luminance that televisions must contain in order to claim HDR compatibility.[14] Some manufacturers are designing televisions with peak luminance levels of only 400 to 500 nits, but delivering black levels so low that the dynamic contrast (difference between brightest and darkest parts of the screen) is quite wide. Others have argued for a peak luminance capability of at least 700 to 1,000 nits, with forecasts of 1,200- to 1,500-nit capabilities on compatible models in the near future.[15] Dolby Vision aspires to deliver a luminance range of 0 to 10,000 nits and has shown a prototype capable of 4,000 nits already, roughly 10 to 13 times brighter than a typical HD TV.[16]

Consensus has been slowly emerging around the software encoding side of HDR to ensure that all HDR-capable televisions can recognize and properly display HDR-encoded video content. The Consumer Electronics Association (CEA) has identified two consensus standards from the Society of Motion Pictures and Television Engineers (SMPTE) for the encoding process that it proposes to make mandatory, and two optional ones that can exist beyond those to deliver additional capabilities. It appears that HDR-encoded data streams will be about 20 percent larger than non-HDR data streams that are otherwise 4K compatible, further boosting computer processing and bandwidth requirements in compliant televisions.[17]

Of the 11 televisions we purchased for testing, three are HDR capable (high-end models from Samsung, LG, and Panasonic), but only the Samsung had completed firmware updates and released compatible HDR-encoded content soon enough to be included in our testing. With 4K Blu-ray still several months away, and with streaming services only beginning to offer HDR-encoded content, we gained access to HDR-encoded movies using Western Digital's recently released My Passport Cinema, a dedicated USB hard drive for 4K movie storage. Only Samsung SUHD televisions are compatible with HDR movies from this hard drive at present, so we could not test across other models for comparative results.

To understand the On-mode power impact of HDR, we tested the Samsung UN55JS9000 using two movies: *Maze Runner* and *Exodus: Gods and Kings*. We assessed the power impact of HDR by testing each movie using two different configurations in the laboratory. In the first configuration, the television played a native 4K HDR movie from the USB drive; in the second, it played the same movie supplied externally from a 1080p Blu-ray disc upscaled by the Blu-ray player to 4K before being sent to the television. We disabled ABC for this testing to eliminate

**Figure 18: On-mode Power Testing on Samsung Model UN55JS9000 with *Exodus: Gods and Kings* (HDR used 40% more power)**



any interaction between high ambient lighting levels caused by HDR luminance and the Samsung TV's ABC sensor.

The two HDR-encoded movies used 47 percent more power, on average, than their non-HDR versions. *Exodus: Gods and Kings* (Figure 18) averaged 106.9 watts without HDR and 149.3 watts with HDR—a 40 percent increase. *Maze Runner* (Figure 19) averaged 92.2 watts without HDR and 145.4 watts with HDR—a 54 percent increase.

Some of the observed difference between the two films' incremental HDR power consumption is likely attributable to different average picture levels (APLs) in each film, and the subjective decisions made by 20th Century Fox about how best to showcase the HDR effect when each film was encoded. Analyzing a portion of the *Exodus* movie (Figure 20) clearly shows similar power levels when APLs are quite low (at 141 and 144 minutes), but much greater differences at high APLs (135 and 147 minutes).

**Figure 19: On-mode Power Testing on Samsung Model UN55JS9000 with *Maze Runner* (HDR used 54% more power)**

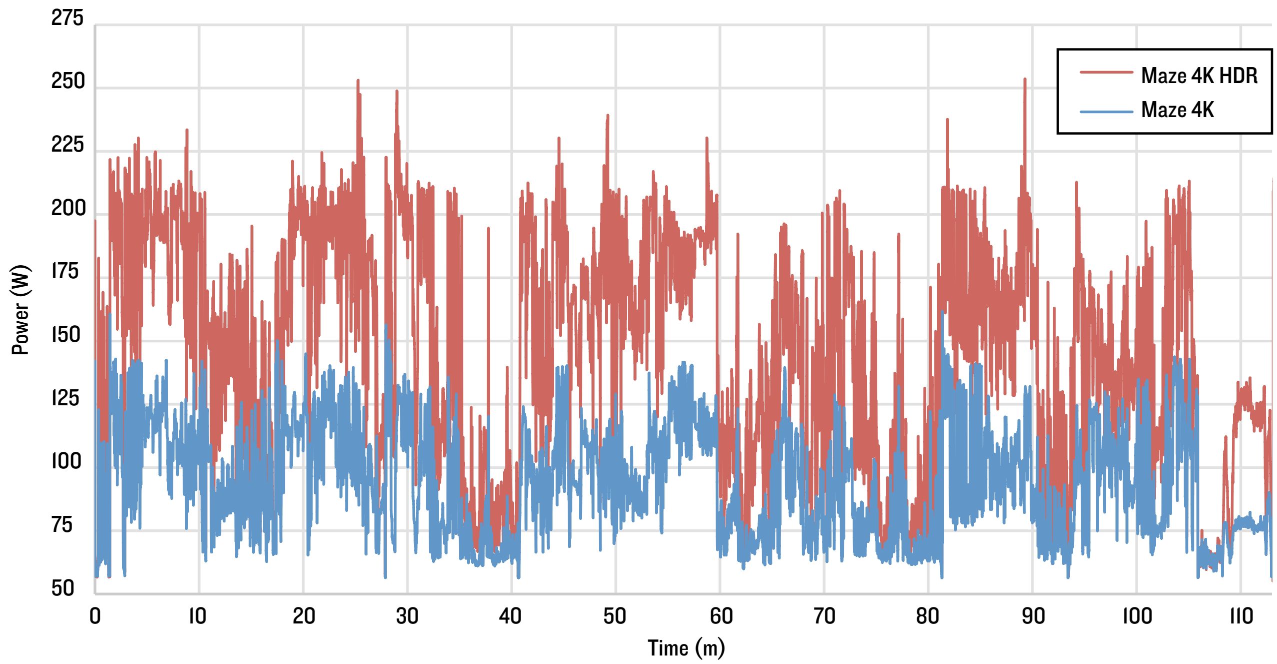
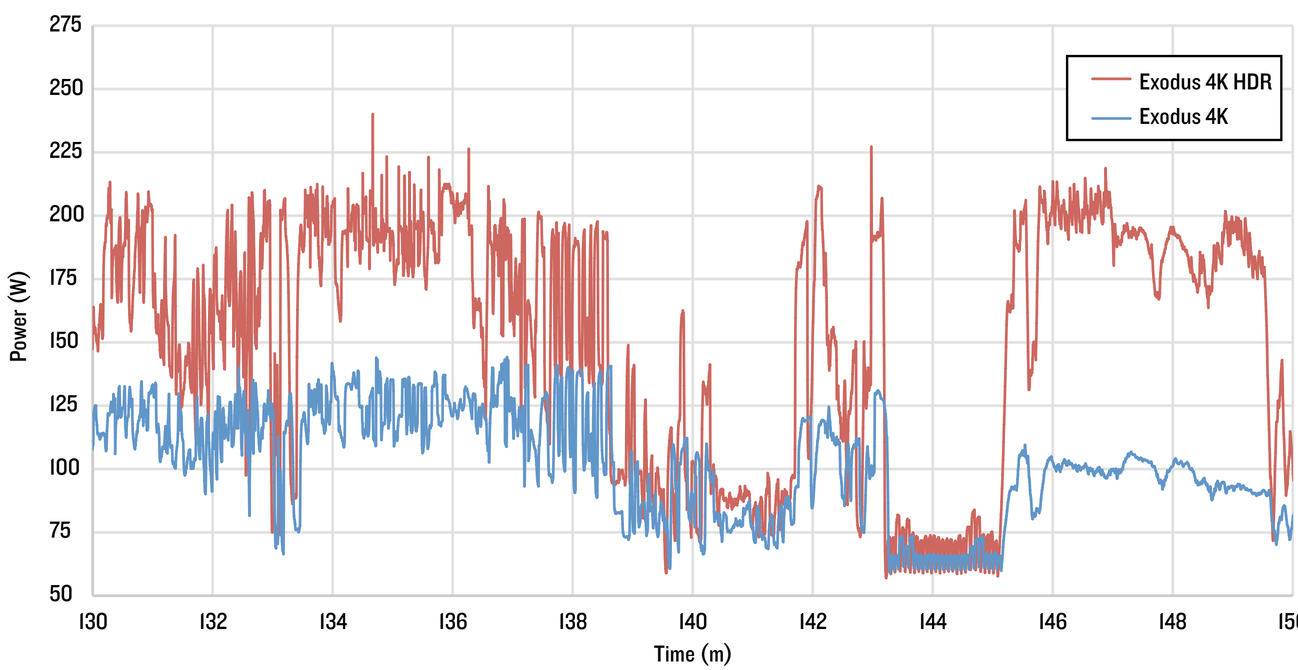



**Figure 20: Close-up Comparison of On-mode Power Variation Between HDR and 4K Versions of Exodus: *Gods and Kings* During 20-Minute Period (Samsung Model UN55JS9000)**



We reached three main conclusions from these initial measurements:

- HDR has the potential to be the most energy consumptive of all the aspects of 4K televisions we have tested so far, particularly as HDR-encoded content proliferates. Right now, the primary energy penalty of HDR capability stems from the fact that HDR-capable televisions tend to deliver higher luminance when displaying non-HDR-encoded content than do 4K TVs that lack HDR capability.
- In most of the televisions we measured, the background power consumption of everything except light production is about 40 to 60 watts. But total power consumption can rise by a factor of three to five from there, depending on how much of the screen is lit and how brightly. HDR TVs capable of 1,000 nits (or more) peak luminance could raise total peak power consumption by a factor of 6 to 10 from the television's background power consumption, to a maximum of roughly 350 to 500 watts for 55-inch models. Continued improvements in LED efficiency will help to mitigate this effect.
- Because televisions without HDR capability ignore the HDR-encoded data, adding HDR-encoded content to the standard IEC test clip will fully reveal the energy efficiency penalty of 4K TVs with HDR capability, while still supporting non-HDR TV models.

## STANDBY POWER LEVELS OF INTERNET-CONNECTED SMART TVS

Standby power is important because a television spends about 19 hours per day in this low-power mode when the owner thinks it is off and is not watching it. (The EPA uses a duty cycle of five hours on and 19 hours standby in its ENERGY STAR specification.) For example, a 10-watt increase in standby power adds up to about 70 kWh/yr. Within the test method, multiple low-power modes correspond to varying levels of processor activity and power consumption. Standby passive is the lowest level of standby, where an Internet-connected television has been turned off by the consumer and is not able to send or receive data. Standby-active low is the state in which a powered-off, network-connected television is in "ready" mode, capable of receiving or sending data from the Internet. When a television is in standby and actively receiving or sending data, such as updating an app or receiving a firmware update, it is in standby-active high mode.

By connecting the television under test to a local area network (WiFi router) not connected to a wide area network (Internet), we ensured that the television did not enter standby-active high mode when performing DOE-specific testing. The overwhelming majority of tested televisions enter standby passive when powered off and stay in that mode until powered on. Unless otherwise stated, standby power in this report refers to standby passive mode.

In addition to examining standby power use, we also measured each model's boot or restart time, which we have defined as the time between the user pressing the power button on the remote control and the TV displaying a picture from an already connected Blu-ray player. Some manufacturers have a quick-start feature to reduce boot time when enabled, but usually at the expense of a significant increase in standby power. Older Sony smart TVs with the first versions of Google TV capability used 24 W in standby with quick-start selected. At 19 hours per day, the standby energy use alone for this model would be 166 kWh/yr, which could double its total annual energy use.

**Table 4: Standby Passive Power Use with Quick-start Enabled and Disabled**

| | | | Quick start Off | | Quick start On | |
|---|---|---|---|---|---|---|
| Year | UHD Model | OS | Standby Power (W) | Boot Time (s) | Standby Power (W) | Boot Time (s) |
| 2015 | HISENSE 50H7GB | Opera | 0.26 | 13.30 | N/A | N/A |
| 2014 | LG 49UB8500 | webOS | 0.10 | 9.0 | N/A | N/A |
| 2015 | LG 55EG9600 | webOS | 0.13 | 9.7 | N/A | N/A |
| 2015 | LG 55UF7600 | webOS | 0.17 | 6.7 | N/A | N/A |
| 2015 | PANASONIC TC55CX850U | Firefox | 0.24 | 8.38 | N/A | N/A |
| 2015 | SAMSUNG UN55JS8500 | Tizen | 0.15 | 6.4 | 0.24 | 5.4 |
| 2015 | SAMSUNG UN55JS9000 | Tizen | 0.07 | 6.2 | 0.20 | 4.5 |
| 2015 | SAMSUNG UN55JU6500 | Tizen | 0.11 | 6.9 | 0.22 | 5.1 |
| 2015 | SAMSUNG UN55JU7100 | Tizen | 0.18 | 6.6 | 0.28 | 5.0 |
| 2015 | SAMSUNG UN65JS9500 | Tizen | 0.07 | 6.1 | 0.20 | 4.7 |
| 2015 | SCEPTRE U500CV | Proprietary | 0.25 | 16.10 | N/A | N/A |
| 2014 | SHARP LC60UD27 | Proprietary | 0.16 | 19.5 | 25.21 | 8.9 |
| 2015 | SHARP LC55UB30U | Proprietary | 0.25 | 17.9 | 9.03 | 5.7 |
| 2014 | SONY XBR55X800B | Proprietary | 0.09 | 12.5 | 34.42(**) | 5.6 |
| 2014 | SONY XBR65X900B | Proprietary | 0.02 | 11.0 | 37.54(**) | 4.0 |
| 2015 | SONY XBR55X850C | Android TV | 0.29/22.1(*) | 8.2 | N/A | N/A |
| 2015 | VIZIO M55-C2 | Proprietary | 0.20 | 15.3 | N/A | N/A |
| 2014 | VIZIO P552ui-B2 | Proprietary | 0.20 | 15.7 | N/A | N/A |

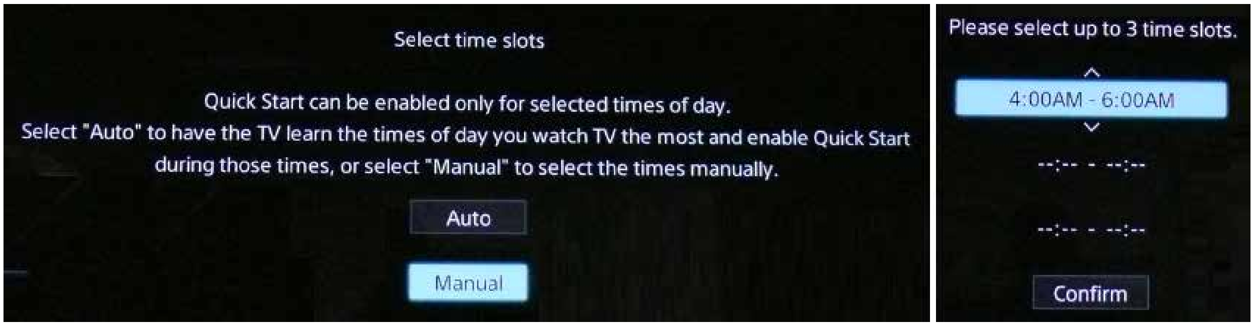
* Fluctuates between Standby passive (0.29W) and active-low (22.1W)

** Programmable quick start up to 6 hours per day or auto settings

**64% less QS standby power than 2014 model**

**Sony eliminated QS in 2015**

**Figure 21: 2014 Sony Quick-start Settings Limit the Duration of High Standby Power Use**

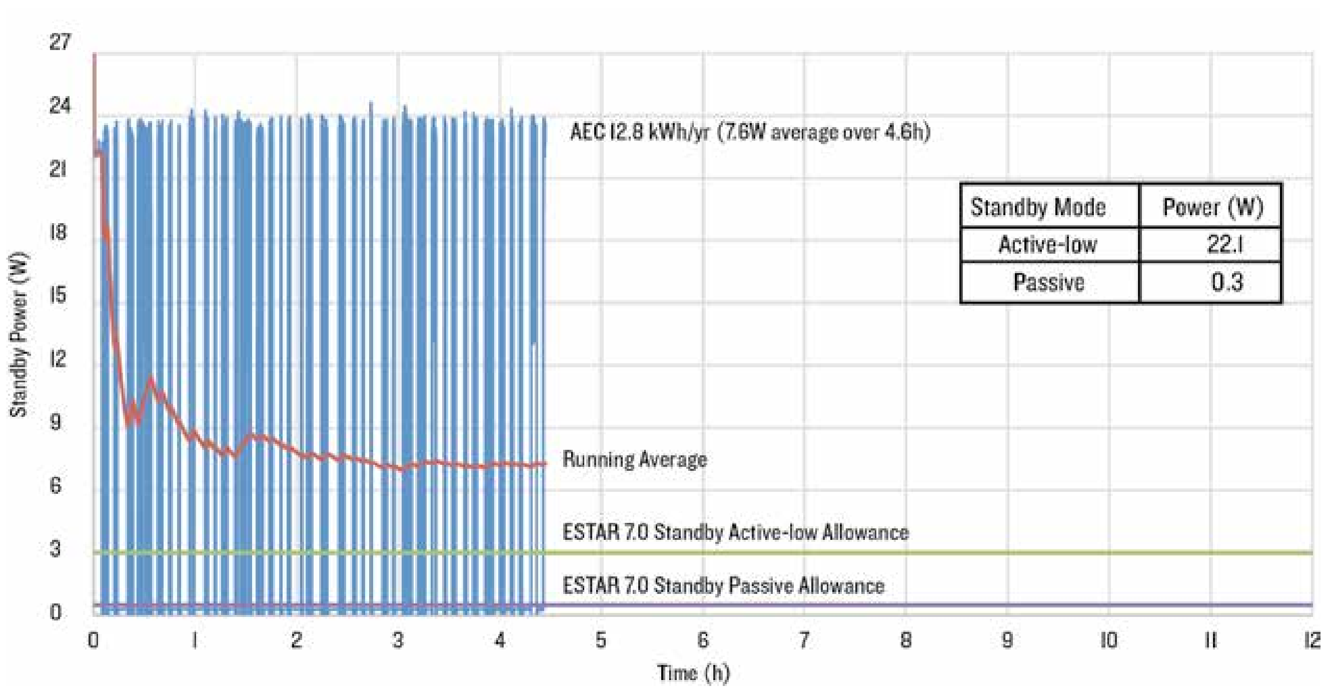



To understand how boot time and standby power levels vary with and without quick-start selected, we tested a range of 2014 and 2015 models both in the lab and in retail locations (Table 4). The Samsung and LG models were the best-performing, with boot times of less than 10 seconds and standby power use of less than 0.3 W. These models did not require quick-start activation to achieve these levels of performance. The Vizio models had a very low standby power level as well, 0.2 W, but with boot times of 15 seconds, or twice as long as other televisions. The Vizio models do not include a quick-start feature. The 2014 Sony and Sharp models had power levels in excess of 25 W when quick-start was selected.

Sharp 2014 and 2015 models tested with quick-start enabled had standby power levels of 25.2 W and 9.03 W, respectively, and boot times of 8.9 seconds and 5.7 seconds, respectively. With quick-start disabled, these televisions had boot times of 19.5 and 17.9 seconds, which may be too long for many consumers. This could cause users to select the quick-start setting, resulting in an extra 62 kWh/yr of standby energy not reported for the 2015 Sharp model under the test method.

The two 2014 Sony models drew a remarkably high 34.4 W and 37.5 W in standby power with quick-start enabled. (While the television was shipped with quick start disabled, some users will turn this feature on if they find the reboot times of 12.5 and 11 seconds to be too slow.) However, these televisions have additional software (Figure 21) that limits the high standby power that was observed when quick start is selected to six hours per day, or allows the television to learn users' viewing times and enable quick-start only when the user is likely to turn on the television. Over the course of a year, this translates to an additional 75 kWh of energy use when the television is switched "off."

**Figure 22: Plot of Power Draw of 2015 Sony TV with Android OS When Switched Off**



The 2015 Sony Model 850C had an 8.2-second boot time, which is likely acceptable for most users, and does not have a quick-start option. While measuring standby power on this model, we observed that standby power cycled between low and higher values. Since this model does not stabilize as fast as the other televisions, we recorded standby power use for an extended period in this mode of operation. The standby power cycled (Figure 22) between 0.29 W (standby passive mode) and 22.1 W (standby-active low mode) for a period of 4.6 hours before stabilizing at 0.29 W. The average power draw during that cycling period was 7.6 W, which translates to 12.8 kWh/yr. This cycling occurs each time the user turns the television from on to off, meaning its annual energy use could be even higher if users watch television in multiple short intervals throughout the day. For example, if the usage pattern for a family entails a parent turning on the television before work, a child watching television or playing a video game during the afternoon, and the parents watching a program in the evening, the standby energy use could be three times this amount, or 38.4 kWh/yr.

Since this television fluctuates between standby-active low (22.1 W) and standby passive (0.3 W) modes, it is difficult to determine which value should be reported. If measurements are not taken until stabilization is reached, then 0.3 W would be reported and the higher power draw of 12.8 kWh/yr—not to mention the 38.4 kWh/yr scenario—would not be included in the AEC calculation. Current test method guidance does not address measuring standby power for smart TV models that fluctuate between standby-active low and standby-passive states. Although this power use fluctuation was detected only on the Sony model we tested, it may become more prevalent, especially as new apps and software are added to new televisions that may cause them to do additional web searches and data downloads when the television is not on for viewing.

## VOICE CONTROL AND ENERGY CONSUMPTION

Many of the higher-end 4K televisions today are equipped with voice control capability. This allows the user to issue operational commands to perform actions such as changing the channel and volume level, and to ask questions that the television will respond to, similar to the Siri interface on Apple iPhones.

In our testing, we encountered two different implementations of the voice control feature. The most popular method requires the user to press a button on the remote, with the television powered on, in order to issue a voice command. In the other method, the television constantly monitors room audio, listening for a keyword that triggers it to process a subsequent command. With this hands-free implementation, the user not only can issue commands with the television powered on, but can also issue a voice command to switch the television on from a standby state.

We developed two test sequences (Table 5) to characterize the incremental power use of voice control when pressing the voice command button. The first sequence established a baseline of how much power the television uses when listening for a command. The second sequence measured power use while responding to a voice command. By using a black static test image, we minimized power use associated with displaying an image and enabled a clear power measurement for voice commands. We performed this testing in the laboratory with low ambient noise levels and connected the televisions to the Internet to allow cloud-based processing as required.

Across all tested televisions, the energy use associated with responding to a voice command did not cause enough incremental computational energy use to affect annual totals meaningfully. Test results for the LG 55UF7600 (Figure 23) show that voice command power use is 22 percent less than measured On-mode power and is attributed primarily to displaying corresponding text and menus on the screen during a voice command sequence.

**Table 5: Voice Control Test Sequences**

| Test Sequence 1 | Duration |
|---|---|
| 1) Voice Command Button Pressed | 4s |
| 2) Exit Menu Button Pressed | N/A |

| Test Sequence 2 | Duration |
|---|---|
| 1) Voice Command Button Pressed | 4s |
| 2) Voice Command Issued | 1s |
| 3) TV Response to Voice Command | 7s |
| 4) Exit Menu Button Pressed | N/A |

**Figure 23: Voice Recognition Activity After Voice Button is Pressed**

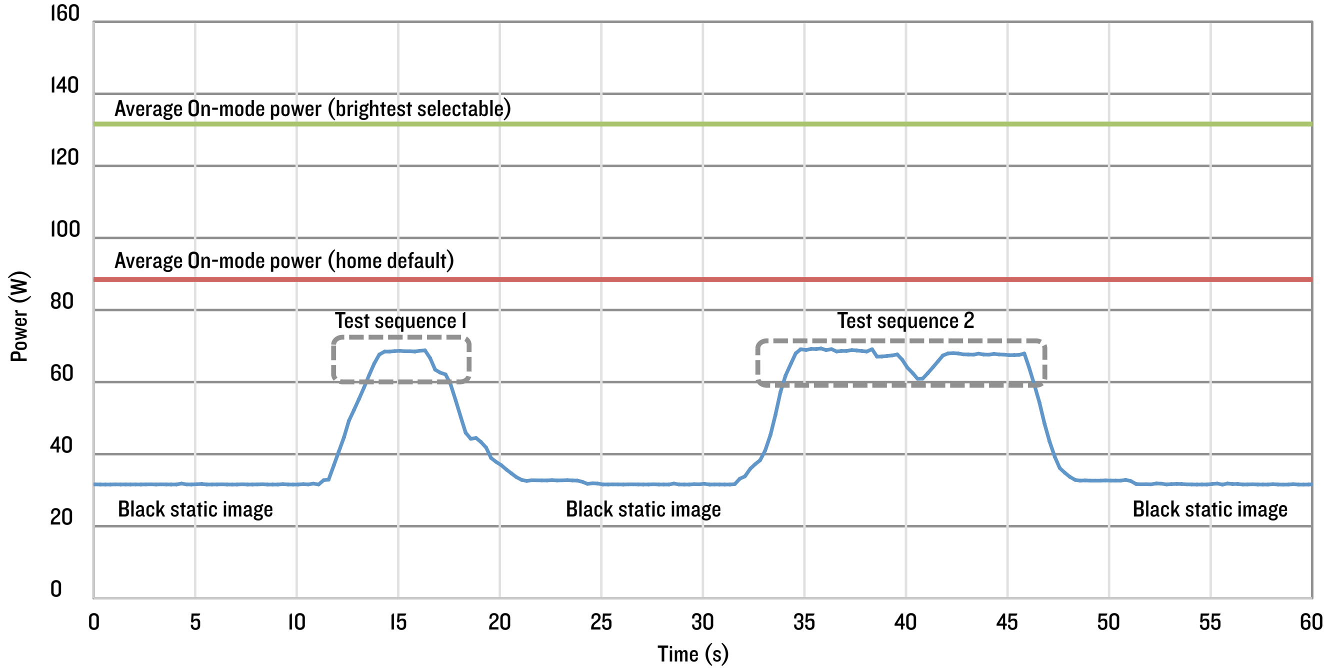
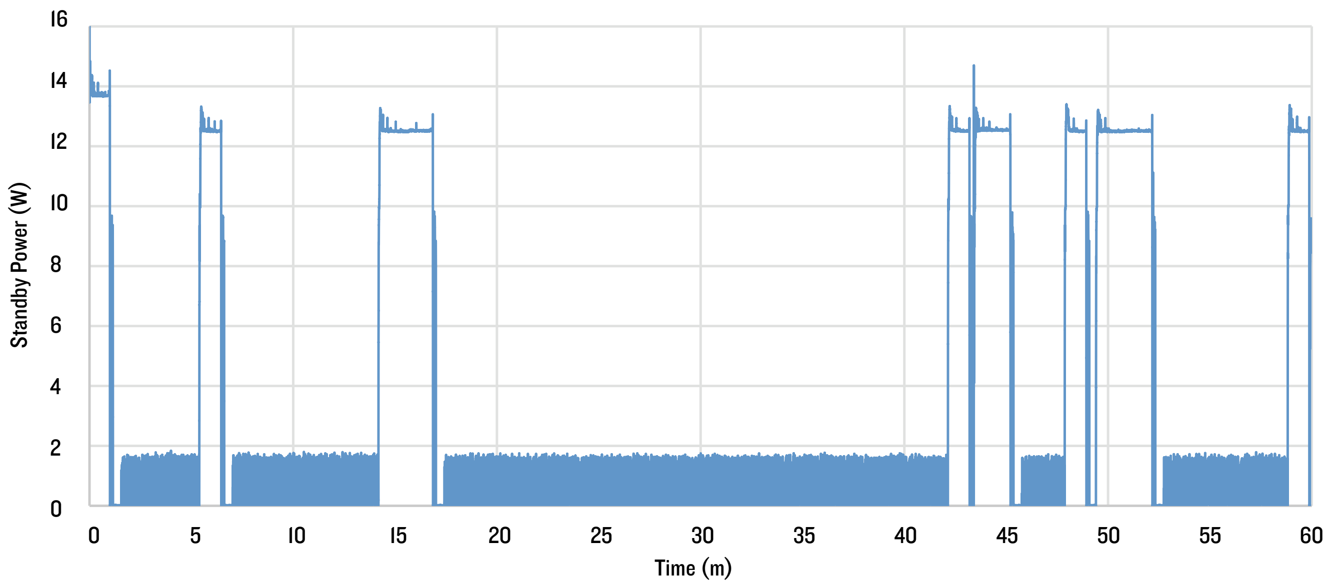



**Figure 24: Panasonic TC55CX850U Power Use in Standby**




The Panasonic TC55CX850U is the only television we tested that has an always-listening voice feature. This feature is disabled by default. When this feature was enabled, the stabilized standby power doubled from 0.24 W to 0.53 W, equating to an extra 2 kWh/yr of AEC. For comparison, the Xbox One game console uses 12 W in standby for always-listening functionality.

When measuring standby power for an extended duration with the always-listening feature enabled, the television fluctuated between standby-active low (network enabled) and standby passive (network disabled) modes (Figure 24). During an hour of measurement, the television drew an average of 3.14 W, or 2.9 W more than its typical standby power of 0.24 W. This equates to a 20 kWh/yr increase in AEC per the DOE-specified 19-hour standby duty cycle. It was not within the scope of this project to determine whether the fluctuation in standby modes is due to voice control or another feature, but the current DOE test method does not consider the extra 20 kWh/yr when reporting energy use.

# *Chapter 4:*
# Key Findings

After completing product testing in retail stores and in the laboratory, reviewing public databases, and conducting extensive market research and analysis on 2014 and 2015 model 4K TVs, we find the following:

**AMERICANS ARE INCREASINGLY BUYING BIGGER SCREEN SIZES AND ACCELERATING THEIR ADOPTION OF THE NEWEST TELEVISION TECHNOLOGIES.** Though average television screen size has been increasing for years, that pace appears to be accelerating with the advent of 4K technology and manufacturer/retailer marketing efforts emphasizing the need for bigger screen size to take advantage of what 4K offers.[18] Per our analysis, just under a third of new televisions sold have a screen size of 50 inches or greater. In addition, televisions with a 50- to 60-inch screen size have become the most popular. Smart functionality appeared in about 40 percent of the models exhibited at retail stores in 2013, but it now appears in more than 60 percent of models and continues to grow in popularity.[19] As other UHD features like HDR, wide color gamut, higher frame rate, and UHD Blu-ray compatibility increasingly appear in retail store demonstrations, and as prices continue to fall, another major wave of upgrades from current owners of HD TVs is likely to occur.[20] Wide color gamut capability appeared in only a small number of models in 2013 and 2014 but will appear in 25 percent of the area of all displays sold in 2015.[21]

**4K TVS USE 30 PERCENT MORE POWER.** Based on a sales-weighted analysis of 2014 and 2015 public data, 4K TVs consumed an average of 30 percent more power than HD TVs. The primary reason is that their backlights need to be brighter to deliver comparable or higher luminance and more vivid colors through a larger number of pixels.

4K TV energy use per model dropped 4 percent, while HD TV energy consumption dropped by 8 percent, between 2014 and 2015. This suggests the efficiency gap between the technologies is not yet closing. If anything, manufacturers are increasingly bundling their most advanced, compelling features with their 4K models, while HD models may be more likely to be sold as lower-cost "value" products without as many features.

**THERE ARE WIDE DIFFERENCES IN ENERGY USE BETWEEN THE BEST AND WORST 4K MODELS OF A GIVEN SIZE.** Our test results confirm that there are remarkable differences in the energy efficiency of comparably sized 4K TVs that are not explained by performance and feature differences alone. The least efficient model we tested used almost three times more power when operating and more energy per year than the most efficient model we tested of comparable size. Differences in standby-mode energy consumption were even greater. This means that 4K TVs are not destined to drive energy consumption upward if we can act now to encourage manufacturers to ensure that all new 4K TVs operate as efficiently as the best current models.

**AUTOMATIC BRIGHTNESS CONTROL GREATLY AFFECTS ON-MODE POWER USE.** In our laboratory testing of 55-inch models, we found that the 4K TVs used an average of 50 percent more power with ABC off than with it on. The range was quite large and varied from 17 percent to 93 percent. For reasons that are unclear, a few models that had an ABC sensor were shipped without ABC enabled. With this simple setting change, the reported energy use for these models could be reduced dramatically, allowing them in some cases to qualify for ENERGY STAR labeling and utility rebates, where available.

**SOME TVS ACHIEVE BOTH LOW STANDBY POWER AND BOOT TIMES, BUT OTHERS HAVE VERY HIGH STANDBY POWER WHEN A QUICK-START FEATURE IS SELECTED.** Many manufacturers have been able to achieve both standby power levels below 0.5 W and restart or boot times of 5 to 10 seconds. A few models had very high standby power levels when quick start was enabled, with one television as high as 37 W for six hours per day. Another television that we tested had widely fluctuating standby power levels and did not stabilize until it had been in standby mode for 4.6 hours. If users enable quick start to avoid long boot times, that will dramatically increase standby-mode energy use, and therefore increase the TV's total annual energy use.

**INCREASING THE RESOLUTION OF THE SOURCE MATERIAL FROM 1080i TO 4K TENDS TO MEANINGFULLY INCREASE THE POWER USE OF 4K TVS.** Average power use rose by 10 percent when the resolution of the source material was increased, but there was wide variation around the value from model to model. This suggests that as native 4K content proliferates in the coming years, the real-world energy use of 4K TVs will be higher than predicted by current federal energy efficiency test procedures.

**STREAMING AND VOICE RECOGNITION DO NOT APPEAR TO HAVE A SIGNIFICANT IMPACT ON 4K TV ENERGY USE SO FAR.** Neither the streaming nor voice recognition features on the televisions we tested meaningfully increased their energy use.

**HDR COULD HAVE THE LARGEST IMPACT ON POWER CONSUMPTION OF ALL UHD FEATURES.** HDR increased On-mode power use by an average of 47 percent in the one HDR model we tested with two different HDR-encoded movies. As movie studios increasingly encode UHD Blu-ray discs and streamed content in HDR, the percentage of time that HDR-capable 4K TVs play HDR-encoded content will rise. In addition, HDR-capable televisions may increasingly "tone map" conventional content to appear more like HDR-encoded content, with unknown energy impacts. HDR and wide color gamut capability are likely to increase sales of 4K TVs more dramatically than their high resolution will, given that their visual impacts are more immediately obvious in showroom demonstrations.[22] Much of the additional energy use of HDR will not be reflected in a model's officially reported energy use until the standard federal test procedure includes native 4K, HDR-encoded content.

**THE POTENTIAL NATIONAL ENERGY IMPACTS OF THE SHIFT TO 4K TVS ARE PROFOUND.** Americans' residential energy bills could rise by more than $1 billion per year if all televisions larger than 36 inches transition to 4K at today's average efficiency. This increase in energy use is equivalent to three times the annual electricity use of all the homes in San Francisco and represents an extra 4 million metric tons of $CO_2$ emissions per year. The good news is that the technology already exists to prevent much of this increased energy use and related impacts, as some of the most efficient 4K TV models on the market today use little to no more power than similar-size HD TVs.

**BEST-PRACTICES ENERGY EFFICIENCY IS READILY ACHIEVABLE.** We found that manufacturers can employ several key strategies to achieve best practices in energy efficiency in 4K TVs:

- Enable automatic brightness control (ABC) by default and design televisions to reduce screen luminance sharply as ambient lighting conditions dim.
- Use local screen dimming to shut off portions of the backlight in areas where no light is needed to improve image quality and reduce on mode power use.
- Employ new high-efficiency strategies for generating and transmitting light, including quantum dots, high-performance LEDs, improved optical films, and more transmissive LCD panels.
- Design the "brains" of smart TVs to boot up quickly and to automatically shut off unnecessary features (power scaling) when not in use to minimize energy consumption in lower power modes.

**THE ENERGY STAR VERSION 7.0 POWER ADDER OF 50 PERCENT FOR 4K TVS IS LARGER THAN NECESSARY FOR TODAY'S MARKET.** While 4K TVs will tend to consume more energy than their HD counterparts, but that difference can be quite modest in the best television designs—certainly far less than the 50 percent additional power allowance (adder) ENERGY STAR currently grants to labeled 4K models.

**USER BEHAVIOR MATTERS MORE THAN EVER.** User choices with regard to display modes, screen brightness, feature selections, and room lighting conditions can significantly affect the annual energy use of televisions, regardless of how efficiently they are designed. It is therefore important to arm users with information about how their behavior can have an impact on energy consumption.

# *Chapter 5:*
# Policy and Program Recommendations

The national energy and environmental consequences of the transition to 4K TV will be profound unless key changes are made to government test procedures, efficiency metrics, labeling specifications, and mandatory standards. Those, in turn, would help drive product design changes by manufacturers to rein in the extra energy use of early 4K technologies and continue their track record of energy savings from each successive generation of televisions.

Based on our findings, we recommend a number of key changes to state and federal government energy policy and utility programs related to televisions:

***1.*** The DOE should update the federal television test method in the following ways:

- Use native 4K Blu-ray source material when testing 4K resolution and HDR encoding in 4K TVs in 2016 and thereafter. This will better reflect conditions likely to exist in actual consumer use.
- Measure standby power use immediately after multiple product shutoffs and for an extended period thereafter, and time-average the resulting values, rather than waiting for power use to stabilize before making a measurement.
- For products that have longer than 10-second boot times and offer a quick-start mode, require that their standby power values be measured with quick start enabled. This will more accurately reflect the way users would typically operate the products.
- Connect televisions to a local area network (LAN) and wide area network (Internet) during standby and active mode testing to more accurately reflect typical usage conditions.
- Consolidate all guidance for lab technicians in one document, rather than in a series of documents from various organizations referencing one another. This will reduce the likelihood of technicians inadvertently measuring products in varying ways.

***2.*** ENERGY STAR should reduce the size of the adder it offers to 4K televisions in its upcoming ENERGY STAR version 8.0 specifications. More extensive data analysis in late 2015/early 2016 will reveal how much lower than 50 percent this level can be while still rewarding well-designed products.

***3.*** The Federal Trade Commission (FTC) should establish a centralized, online version of the EnergyGuide label with more up-to-date comparative information than is now on the mandatory TV labels. The FTC currently updates the range of minimum and maximum energy use for televisions of a given size so infrequently that individual models often display an expected energy use outside the quoted range. The FTC should also provide 10-year lifetime operating cost information, rather than simply annual information on the EnergyGuide label, to help motivate buyers to choose more-efficient models.

***4.*** The California Energy Commission (CEC) should consider revising its mandatory efficiency standards for televisions to reflect recent progress in television technology and extend these standards to the largest screen sizes, which are exempted. Currently, in the absence of state or federal regulations, manufacturers whose televisions slightly miss the ENERGY STAR requirements may have few incentives to make them relatively more efficient. Instead, they might choose to make the televisions much brighter to attract interest from buyers or use lower-quality, less expensive components to save money, with corresponding losses of efficiency. This helps explain why many of the largest models today now use hundreds of watts of power.

***5.*** Utilities should design incentive programs to reward products at the most efficient level or, at the very least, at some percentage better than ENERGY STAR. This will be important to ensure that rebates draw the market toward best practices rather than to products that offer only modest energy savings over typical levels.

***6.*** Utility program design staff should consider adopting voluntary supplemental television testing requirements for models to qualify for the highest level of utility incentives and promotion. These tests would measure aspects of television performance and energy use not captured in current government test procedures and would ensure that the best televisions continue to deliver energy savings under a wider range of expected usage conditions.

***7.*** Manufacturers and retailers should provide more detailed guidance to consumers about how to operate televisions efficiently. Many of these suggestions would improve picture quality as well.

***8.*** Researchers should conduct further investigations in several areas. Specifically, they should:

- ***Conduct comprehensive HDR measurements.*** Early evidence suggests that HDR TVs can draw more power than similarly equipped non-HDR TVs, even when displaying non-HDR-encoded content. They have higher luminance capabilities and can extrapolate from the information in non-HDR content to varying degrees to create an HDR-like effect via tone mapping.[23] It would be worthwhile to test this hypothesis on multiple HDR televisions from different manufacturers, and then test those same televisions with HDR and non-HDR-encoded versions of the same video content to further refine our estimate of incremental energy use associated with HDR. If HDR televisions draw more power than non-HDR televisions even when displaying conventional content, the energy-use implications as HDR proliferates will be even greater than today's rare HDR content would suggest.

- ***Examine increased data flow and its overall energy impacts.*** Our initial testing suggests that the newest television designs are capable of very high streaming data rates. This will in turn increase data throughput and associated energy use at data centers, service providers, and the devices that bring Internet access into the home and distribute it wirelessly. However, the newest smart TVs also send and receive significant amounts of data, at least episodically, when in standby mode. This includes program guide information, updates to internal apps and firmware, newsworthy sports and financial information, data about the programs that users have been watching and the words they have spoken in the presence of a television with voice command capability.[24] To better understand energy impacts, it would be worthwhile to conduct additional measurements of how much data and what types of data are being sent and received during the various parts of a smart TV's duty cycle.

- ***Benchmark automatic brightness control (ABC) systems to determine energy savings and picture quality impacts.*** Manufacturers currently receive energy savings credit for implementing ABC and reducing screen luminance at various specified room illuminance levels. However, it would be worthwhile to determine the extent to which some televisions dim their screens more dramatically than others in response to a given change in room illuminance, and to investigate whether those changes adversely affect picture quality enough to encourage users to disable ABC and forgo its energy savings.

# *Appendix A:*
# Test Methodology

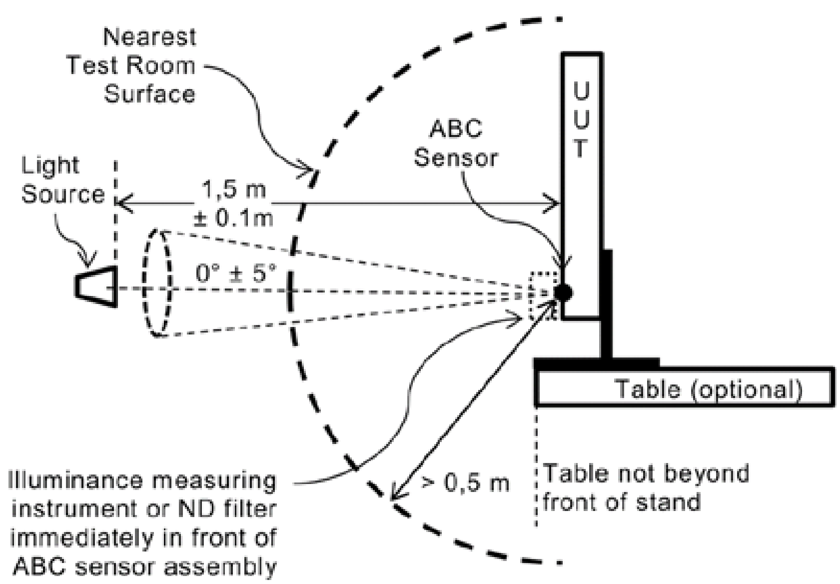
We performed lab testing using ENERGY STAR 6.1 and the DOE final rule as the primary specifications, with ENERGY STAR 7.1, DOE NOPR, and CEA 2037 referenced for additional guidance as necessary. Table 6 contains a complete list of supporting documents. The primary tools used for power and luminance measurements were the IEC broadcast and 3bar static pattern, part of the IEC 62087 Ed. 3.0 Blu-ray disc. Figure 25 shows the configuration used for ABC testing. In addition to standardized tests, we performed supplemental testing to characterize energy usage for modes and features not covered by the DOE test procedure, including 4K native resolution playback, streaming Internet media, voice control, and quick start.

Retail testing was based on the lab test procedure but also used an accelerated test method that eliminated tests and reduced stabilization times when appropriate. Similar to lab testing, the IEC broadcast and 3bar pattern are the primary tools used during measurements, with supplemental tests performed in order to characterize energy usage for modes and features not covered by the DOE test procedure. Since we could not control ambient light in a retail environment, we disabled the automatic brightness control (ABC) sensor on each television prior to taking measurements.

**Table 6: Test Method Guidance Documents**

| Document | Description |
|---|---|
| IEC 62087 Ed. 3.0 | Methods of measurement of the power consumption of audio, video, and related equipment |
| IEC 62087 Ed. 3.0 Blu-ray disc | Video content for IEC 62087 Ed. 3.0 on Blu-ray disc |
| IEC 62301 Ed. 2.0 | Household electrical appliances—measurement of standby power |
| CFR Appendix H to Subpart B of Part 430 | Uniform test method for measuring the power consumption of television sets |
| Final Rule [78 FR 63823] | DOE test procedure for television sets; final rule |
| NOPR [77 FR 2864] | DOE test procedure for television sets; notice of proposed rulemaking |
| ENERGY STAR version 6.1 | Program requirements for televisions: eligibility criteria |
| ENERGY STAR version 7.0 | Program requirements for televisions: eligibility criteria |
| CEA-2037A | Determination of television set power consumption July 2014 (with 2/2/2015 correction) |

**Figure 25: ABC test setup referenced from CEA-2037A**



## *Appendix B:*
# Test Equipment

All test equipment (Table 7) held valid calibration certificates at the time of testing and met or exceeded tolerances defined by the DOE Final Rule 78 FR 63823.

**Table 7: Test Equipment List**

| Type | Make | Model | S/N | Calibration Date |
|---|---|---|---|---|
| AC power source | Chroma | 61620 | 616020002628 | 03/23/15 |
| Power analyzer | Yokogawa | WT310-D-C1/G5 | C2RA21009V | 03/26/15 |
| Power meter | Watts Up? | PRO | | |
| Luminance meter | SpectraCal | C6 | SP-15.A-02.102023.03 | 03/23/15 |
| Illuminance meter | Konica | T-10 | 36921049 (Body)<br>55931079 (Head) | 04/15/15 |
| Blu-ray player | OPPO | BDP-103 | B242U01435045057 | N/A |
| Lamp | Satco | S2237 | N/A | N/A |

## *Appendix C:*
# National Energy Impact Methodology

### ANNUAL ENERGY CONSUMPTION (AEC) ASSUMPTIONS

We partnered with the Northwest Energy Efficiency Alliance (NEEA) and its consultant Energy Solutions to perform dataset analysis based on model-specific market data provided by the data collection firm NPD for the Pacific Northwest. To calculate sales-weighted AEC values by screen size bin, Energy Solutions matched sales and AEC values to models representing 95 percent of sales. To estimate the AEC of the many models representing the remaining 5 percent of sales, Energy Solutions used a linear regression of the ENERGY STAR 7 test dataset to estimate AEC values by screen size along with the assumption that standby power was 0.4W. NEEA's approach assumed a duty cycle of 5.2 hours on and 18.8 hours in standby. This assumption is based on a PG&E-commissioned Nielsen study from 2012, done prior to the DOE study that settled on five hours of television use per day. NEEA continues to use the 5.2-hour duty cycle to maintain long-term continuity. One implication of aligning with NEEA's duty cycle is that the average AEC values calculated in the dataset analysis are based on the assumption that televisions are on for 5.2 hours per day, whereas we assumed 5 hours in on mode for our measured AEC values, consistent with the DOE test method.

### SUPPORTING DATA

The tables that follow, based on Pacific Northwest data shared by NEEA, provide insight into our national impact analysis calculations. Table 8 shows the supporting AEC values used to calculate the energy penalty percentages by bin. Weighting by 4K sales percentages, we computed the 4K TV energy penalty for 2014 and 2015. When averaged, the resulting penalty—or additional energy use—is 30 percent.

| Table 8: 4K Penalty Source Data | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2014** | **< 32** | **32-35** | **36-39** | **40-46** | **47-49** | **50-60** | **> 60** | **Wtd. Avg.** |
| **HD** | | | | | | | | |
| Avg. AEC (kWh/yr) | 51 | 72 | 90 | 106 | 118 | 153 | 233 | |
| Avg. size (inches) | 24.4 | 32 | 39 | 41.6 | 47.7 | 54.6 | 67.4 | |
| **4K** | | | | | | | | |
| Avg. AEC (kWh/yr) | - | - | 128 | 96 | 176 | 209 | 251 | |
| Avg. size (inches) | - | - | 39 | 40 | 49 | 54.1 | 66.2 | |
| 4K % energy penalty | - | - | 43% | -10% | 49% | 36% | 8% | 26% |
| 4K % of total 4K sales | - | - | 4% | 3% | 3% | 58% | 32% | |
| | | | | | | | | |
| **2015** | **< 32** | **32-35** | **36-39** | **40-46** | **47-49** | **50-60** | **> 60** | **Wtd. Avg.** |
| **HD** | | | | | | | | |
| Avg. AEC (kWh/yr) | 47 | 66 | 83 | 99 | 109 | 142 | 215 | |
| Avg. size (inches) | 24.5 | 32 | 39 | 41.3 | 48 | 54.5 | 66.8 | |
| **4K** | | | | | | | | |
| Avg. AEC ( kWh/yr) | - | - | 128 | 126 | 147 | 201 | 224 | |
| Avg. size (inches) | - | - | 39 | 41.2 | 48.7 | 54 | 66.7 | |
| 4K % energy penalty | - | - | 54% | 28% | 34% | 41% | 4% | 33% |
| 4K % of total 4K sales | - | - | 2% | 9% | 7% | 64% | 19% | |

Table 9 details the calculations for the national impact assessment. We used the 2015 average AEC values by bin (Table 8) weighted by total TV sales (expressed as a percentage in Table 9). Scenario A used HD AEC values for all bins, while Scenario B used HD AEC values for the first two bins and 4K AEC values for the remaining ones (Table 9). One can see that the average screen size, calculated using the same weighting approach, remains constant across the two scenarios at 41 inches.

| Table 9: Average AEC And Screen Size Calculations In Support of National Impact Table | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **National Impact Supporting Calculations** | | | | | | | | |
| **2015** | **< 32** | **32-35** | **36-39** | **40-46** | **47-49** | **50-60** | **> 60** | **Wtd. Avg.** |
| Scenario B: 4K > 36" | HD | HD | 4K | 4K | 4K | 4K | 4K | |
| % of total TV sales | 14% | 25% | 8% | 18% | 5% | 26% | 4% | |
| Avg. AEC (kWh/yr) | 47 | 66 | 128 | 126 | 147 | 201 | 224 | |
| Avg. size (inches) | 24.5 | 32 | 39 | 41.2 | 48.7 | 54 | 66.7 | |
| Scenario A: HD sales weighted avg. AEC | | | | | | | | 99 |
| Scenario A: HD sales weighted avg. screen size | | | | | | | | 41 |
| 4K sales weighted avg. AEC (not used in national impact comparison) | | | | | | | | 194 |
| 4K sales weighted avg. screen size (not used in national impact comparison) | | | | | | | | 55 |
| Scenario B: 4K > 36" sales weighted avg. AEC | | | | | | | | 125 |
| Scenario B: 4K > 36" sales weighted avg. screen size | | | | | | | | 41 |

Table 10 shows the values we used in calculating the year-to-year improvement in energy consumption for HD and 4K TVs. First, we calculated the percentage improvement in AEC by bin for both HD and 4K. Next, we calculated the percentage of sales by bin, based on total projected sales for 2015. Finally, we weighted the individual bin improvement percentages by the individual bin sales percentages. The resulting values express the overall average rate of improvement for both HD and 4K. While HD improvements are consistent across bins, 4K improvements vary widely by bin and are likely caused by smaller sample sizes (sales and model counts) relative to HD.

**Table 10: Source Data—Year-to-Year Improvement for HD and 4K**

| 2014 HD | < 32 | 32-35 | 36-39 | 40-46 | 47-49 | 50-60 | > 60 | Wtd. Avg. |
|---|---|---|---|---|---|---|---|---|
| Avg. AEC | 51 | 72 | 90 | 106 | 118 | 153 | 233 | |
| Avg. size | 24.4 | 32 | 39 | 41.6 | 47.7 | 54.6 | 67.4 | |
| 2015 HD | < 32 | 32-35 | 36-39 | 40-46 | 47-49 | 50-60 | > 60 | |
| Avg. AEC | 47 | 66 | 83 | 99 | 109 | 142 | 215 | |
| Avg. size | 24.5 | 32 | 39 | 41.3 | 48 | 54.5 | 66.8 | |
| YTY % improvement | 9% | 9% | 8% | 7% | 8% | 8% | 8% | 8% |
| 2015 % of HD sales | 16% | 28% | 8% | 19% | 5% | 22% | 2% | |
| **2014 4K** | **< 32** | **32-35** | **36-39** | **40-46** | **47-49** | **50-60** | **> 60** | **Wtd. Avg.** |
| Avg. AEC | - | - | 128 | 96 | 176 | 209 | 251 | |
| Avg. size | - | - | 39 | 40 | 49 | 54.1 | 66.2 | |
| 2015 4K | < 32 | 32-35 | 36-39 | 40-46 | 47-49 | 50-60 | > 60 | |
| Avg. AEC | - | - | 128 | 126 | 147 | 201 | 224 | |
| Avg. size | - | - | 39 | 41.2 | 48.7 | 54 | 66.7 | |
| YTY % improvement | - | - | 0% | -24% | 20% | 4% | 12% | 4% |
| 2015 % of 4K sales | - | - | 2% | 9% | 7% | 64% | 19% | |

# *Appendix D:*
# Detailed Data Tables

Table 11 through Table 13 contain complete test results for all lab-tested and in-store-tested televisions. The light blue cells indicate values reported by the DOE method that is dependent on default settings and forced menu selections.

**Table 11: Data for On-mode Power**

| | Lab/Retail | Power_100 lux | Power_35 lux | Power_12 lux | Power_3 lux | Power_on ABC_calc | Power_on ABC_off | Power_on_4K ABC_off |
|---|---|---|---|---|---|---|---|---|
| HISENSE 50H7GB | Lab | 94.6328 | 94.6225 | 62.5611 | 62.6530 | 78.6173 | 94.6439 | N/A |
| LG 55EG9600 | Lab | 133.7671 | 106.3916 | 98.2034 | 96.3283 | 108.6726 | 136.3174 | N/A |
| LG 55UF7600 | Lab | 65.5522 | 47.3875 | 40.7398 | 39.3759 | 48.2639 | 88.4663 | N/A |
| PAN TC55CX850U | Lab | 178.7062 | 115.4620 | 85.7473 | 76.6537 | 114.1423 | 151.9963 | N/A |
| SAM UN55JS9000 | Lab | 104.2456 | 75.4635 | 65.7119 | 65.7319 | 77.7882 | 125.0038 | N/A |
| SAM UN55JU7100 | Lab | 87.2320 | 56.8719 | 48.1002 | 48.1215 | 60.0814 | 99.9406 | N/A |
| SHARP LC55UB30U | Lab | N/A | N/A | N/A | N/A | N/A | 97.7050 | N/A |
| SCEPTRE U500CV | Lab | N/A | N/A | N/A | N/A | N/A | 97.1211 | N/A |
| SONY XBR55X850C | Lab | 105.1986 | 100.1729 | 82.4197 | 78.4926 | 91.5710 | 107.5732 | N/A |
| VIZIO M55-C2 | Lab | 84.8233 | 68.3260 | 58.7389 | 58.7432 | 67.6579 | 130.2546 | N/A |
| VIZIO P552ui-B2 | Lab | 141.6731 | 108.8552 | 92.0645 | 87.1041 | 107.4242 | 166.3153 | N/A |
| LG 49UB8500 | Retail | N/A | N/A | N/A | N/A | N/A | 92.5075 | 92.0508 |
| LG 55EC9300 | Retail | N/A | N/A | N/A | N/A | N/A | 91.6843 | N/A |
| LG 55UF7600 | Retail | N/A | N/A | N/A | N/A | N/A | 86.3518 | 87.5543 |
| SAM UN55JS8500 | Retail | N/A | N/A | N/A | N/A | N/A | 100.3730 | 100.2006 |
| SAM UN55JU6500 | Retail | N/A | N/A | N/A | N/A | N/A | 89.0443 | 101.3588 |
| SAM UN55JU7100 | Retail | N/A | N/A | N/A | N/A | N/A | 101.5488 | 108.3847 |
| SAM UN65JS9500 | Retail | N/A | N/A | N/A | N/A | N/A | 145.2564 | 213.2566 |
| SHARP LC60UD27 | Retail | N/A | N/A | N/A | N/A | N/A | 169.5099 | 177.1866 |
| SONY XBR55X800B | Retail | N/A | N/A | N/A | N/A | N/A | 83.0350 | 86.8675 |
| SONY XBR65X900B | Retail | N/A | N/A | N/A | N/A | N/A | 181.7682 | 204.1545 |

| Table 12: Data for Standby, Quick Start, and AEC | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Lab/Retail | L_Default Home | L_Brightest Home | Power_black_ static | Power_on_ brightest ABC_off | Power_ crouching 4K_Netflix | Power_ crouching 4K_Oppo | T_boot Netflix menu |
| HISENSE 50H7GB | Lab | 322.5490 | 400.5550 | 33.8645 | 123.5160 | 92.0447 | 92.0447 | 32.8 |
| LG 55EG9600 | Lab | 177.9250 | 227.0530 | 79.5843 | 198.3757 | 127.9882 | 127.6652 | 26.2 |
| LG 55UF7600 | Lab | 324.8290 | 346.1720 | 31.4038 | 131.6074 | 78.5805 | 79.6473 | 23.6 |
| PAN TC55CX850U | Lab | 453.7680 | 526.6550 | 47.6750 | 190.4510 | N/A | N/A | 21.6 |
| SAM UN55JS9000 | Lab | 289.3590 | 443.8320 | 55.9307 | 215.6466 | 118.1857 | 119.4064 | 7.4 |
| SAM UN55JU7100 | Lab | 332.2240 | 420.8780 | 39.0115 | 183.0088 | 94.3284 | 85.9851 | 10.5 |
| SHARP LC55UB30U | Lab | 365.2110 | 386.1880 | 27.1300 | 123.8549 | 99.7494 | 98.9513 | 42.5 |
| SCEPTRE U500CV | Lab | 268.7260 | 290.8920 | 95.3000 | 102.8888 | N/A | N/A | N/A |
| SONY XBR55X850C | Lab | 251.6430 | 360.1250 | 36.2179 | 164.5444 | 89.0126 | 83.2130 | 8.5 |
| VIZIO M55-C2 | Lab | 321.7790 | 411.1770 | 45.1957 | 162.0673 | 100.9319 | 100.2254 | 34.9 |
| VIZIO P552ui-B2 | Lab | 427.0220 | 542.1310 | 50.5977 | 203.5240 | 133.6587 | 159.3858 | 28.1 |
| LG 49UB8500 | Retail | 262.1090 | 372.6800 | 49.5100 | N/A | N/A | N/A | N/A |
| LG 55EC9300 | Retail | 220.9430 | 167.0380 | 48.1283 | N/A | N/A | N/A | N/A |
| LG 55UF7600 | Retail | 304.0230 | 337.2570 | 31.1091 | N/A | N/A | N/A | N/A |
| SAM UN55JS8500 | Retail | 345.5090 | N/A | 37.7700 | N/A | N/A | N/A | N/A |
| SAM UN55JU6500 | Retail | 299.7390 | 384.3230 | 37.1464 | N/A | N/A | N/A | N/A |
| SAM UN55JU7100 | Retail | 327.0920 | 410.5350 | 41.7542 | N/A | N/A | N/A | N/A |
| SAM UN65JS9500 | Retail | 310.3720 | N/A | 67.9450 | N/A | N/A | N/A | N/A |
| SHARP LC60UD27 | Retail | 300.2040 | 408.5440 | 78.4067 | N/A | N/A | N/A | N/A |
| SONY XBR55X800B | Retail | 76.2590 | 347.8500 | 52.4342 | N/A | N/A | N/A | N/A |
| SONY XBR65X900B | Retail | 267.5260 | 403.6700 | 61.6192 | N/A | N/A | N/A | N/A |

| Table 13: Data Luminance and 4K Resolution | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Lab/Retail | P_standby QS_off | T_boot QS_off | P_standby QS_on | T_boot QS_on | AEC ABC_on | AEC ABC_off |
| HISENSE 50H7GB | Lab | 0.2556 | 13.3 | N/A | N/A | 145.2492 | 174.4977 |
| LG 55EG9600 | Lab | 0.1330 | 9.7 | N/A | N/A | 199.2498 | 249.7015 |
| LG 55UF7600 | Lab | 0.1731 | 6.7 | N/A | N/A | 89.2820 | 162.6515 |
| PAN TC55CX850U | Lab | 0.2430 | 8.4 | N/A | N/A | 209.9949 | 279.0785 |
| SAM UN55JS9000 | Lab | 0.0691 | 6.2 | 0.1956 | 4.5 | 143.3200 | 229.4884 |
| SAM UN55JU7100 | Lab | 0.1765 | 6.6 | 0.2822 | 5.0 | 111.6056 | 184.3487 |
| SHARP LC55UB30U | Lab | 0.2540 | 17.9 | 9.0328 | 5.7 | N/A | 180.0731 |
| SCEPTRE U500CV | Lab | 0.2454 | 16.1 | N/A | N/A | N/A | 189.4740 |
| SONY XBR55X850C | Lab | 0.2851 | 8.2 | N/A | N/A | 169.0944 | 198.2985 |
| VIZIO M55-C2 | Lab | 0.1988 | 15.3 | N/A | N/A | 124.8544 | 239.0935 |
| VIZIO P552ui-B2 | Lab | 0.2013 | 15.7 | N/A | N/A | 197.4452 | 304.9214 |
| LG 49UB8500 | Retail | 0.0967 | 9.0 | N/A | N/A | N/A | 169.4969 |
| LG 55EC9300 | Retail | 0.0914 | 7.5 | N/A | N/A | N/A | 167.9577 |
| LG 55UF7600 | Retail | 0.1718 | 6.7 | N/A | N/A | N/A | 158.7833 |
| SAM UN55JS8500 | Retail | 0.1460 | 6.4 | 0.2429 | 5.4 | N/A | 184.8652 |
| SAM UN55JU6500 | Retail | 0.1078 | 6.9 | 0.2172 | 5.1 | N/A | 164.0121 |
| SAM UN55JU7100 | Retail | 0.1641 | 6.5 | 0.2676 | 5.9 | N/A | 187.1824 |
| SAM UN65JS9500 | Retail | 0.0696 | 6.1 | 0.1978 | 4.7 | N/A | 266.4647 |
| SHARP LC60UD27 | Retail | 0.1586 | 19.5 | 25.2074 | 8.9 | N/A | 310.4555 |
| SONY XBR55X800B | Retail | 0.0888 | 12.5 | 34.4165 | 5.6 | N/A | 152.1548 |
| SONY XBR65X900B | Retail | 0.0200 | 11.0 | 37.5400 | 4.0 | N/A | 331.8657 |

ENDNOTES

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4 Sales of some models were higher than sales of others, so in order to estimate the average annual energy consumption of TVs sold within each bin, we calculated a sales-weighted average by model. This approach yielded an outcome significantly different from a calculation of simple averages (not sales-weighted) for each bin.

5 Because 4K TVs are larger on average than HD TVs, the energy use of the average 4K TV would actually be more than 30 percent higher than that of the average HD TV.

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9 Table 1 sources:

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13 It may seem counterintuitive that the TVs we measured used more power when fed a native 4K signal, since this input mode precludes the need for the TV to transcode from HD to 4K for display on the 4K panel. The reason for this is uncertain, but the amount of data delivered to the TV from a native 4K signal is higher, which could increase data processing energy use.

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15 May, Steve, "Sign of the Telly Times: HDR Shines, UHD Blu-Ray Slides at IFA," *The Register*, September 10, 2015, www.theregister.co.uk/2015/09/10/breaking_fad_hdr_shines_and_uhd_blu_ray_slides_at_ifa_2015/ (accessed October 2, 2015).

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