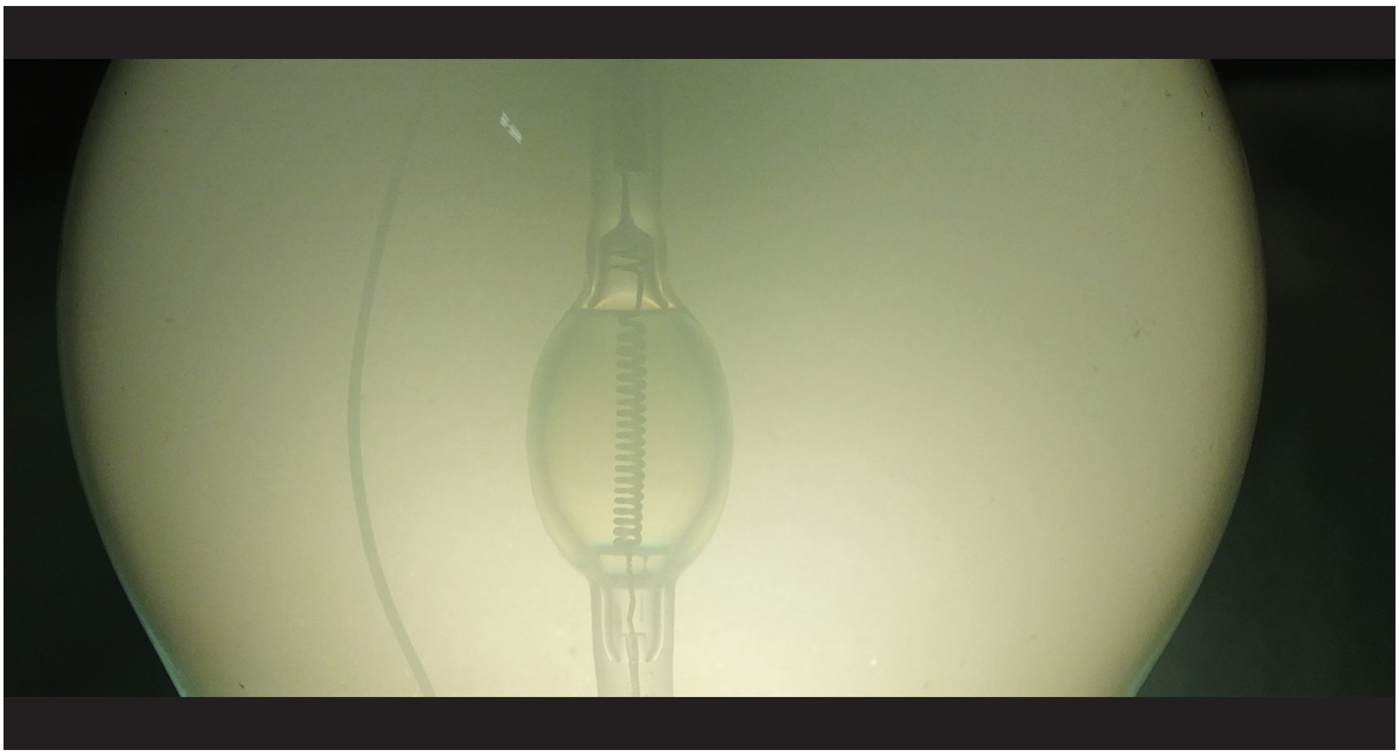
ELECTRIC POWER RESEARCH INSTITUTE

WHOLE PRODUCT PERFORMANCE FOR 2X HIGH-EFFICIENCY INCANDESCENT LAMPS



November 2012

EXECUTIVE SUMMARY

According to the U.S. EPA's Report on "Opportunities to Advance Efficient Lighting" *from October 2011, "Approximately three out of four light sockets in the U.S. still contain inefficient light bulbs. These inefficient light bulbs consume approximately 200 billion kWh per year, resulting in over 140 million metric tons of CO_2 emissions. Programs promoting compact fluorescent lamps (CFLs) have made significant strides; cost effective energy savings from CFLs have been enormous over the last 20 years. However, more than 70% of screw base sockets are still occupied with inefficient bulbs. The implementation of the Energy Independence and Security Act (EISA) will improve things some, but it will not cause a dramatic shift to more efficient lighting. Going forward, CFLs will continue to play an important role in efficiency program energy savings, but will need to be steadily joined by a set of complementary technologies, each suited to particular applications and situations, to form a portfolio of lighting solutions to fill the vast number of remaining sockets.[1]".*

To help address this portfolio approach of advanced lighting technologies, FirstEnergy (FE) approached EPRI's Lighting Lab in 2011 to validate the performance of a newly developed "2X" incandescent lighting technology developed by a manufacturing company in their service territory. This manufacturer claimed that their product was identical in light output, but twice (2X) as efficient as traditional 100W incandescent bulbs. As part of this collaborative work with FE, EPRI conducted a series of tests to independently verify the energy & photometric performance of this innovative new lighting alternative. This research confirmed that the 2X incandescent lamp performs similarly to the standard 100 watt incandescent in most aspects of power, photometric performance, and lifespan (exceeding the manufacturers' specifications). The 2X incandescent was also found to offer some additional features not typically found in conventional CFL's such as temperature independence, improved color rendition, and safe operation using conventional dimmers. This testing provided the necessary verification required by FirstEnergy to potentially include this advanced lighting technology in future energy efficiency program offerings.

[1] *Source: U.S. EPA Report on Opportunities to Advance Efficient Lighting (October 2011, page 1). http://www.energystar.gov/ia/partners/manuf_res/downloads/lighting/EPA_Report_on_NGL_Programs_for_508.pdf*

RESEARCH PROJECT OVERVIEW

Incandescent Technology

The incandescent light bulb, or incandescent lamp, is a device which produces light by passing electrical current through a filament, and heating it to a high temperature until it glows. This filament can be made of many metals, but carbon and tungsten are the most common today.

The evolution and development of the incandescent lamp in the 1800's, and the solidification of an established design later that century, lead to it becoming the primary means of delivering light in many industries well into the 1950's, and in the home for over 100 years. This popularity created a large marketplace with many manufacturers which kept prices of incandescent lamps low and made it difficult for other technologies to enter certain marketplace segments. Over time, technologies like linear fluorescents and HID (High Intensity Discharge) lamps gained majority market share in commercial, industrial, and exterior applications due to their long life, ruggedness, high lumen output, and improved efficacy[2]. In the residential market, the incandescent remained the dominate lamp throughout the 20th century.

Eventually, via market forces and research, a standard filament thickness and operating amperage / voltage were developed to allow for incandescent operation to be measured against established values. A base of 1,000 hours of operation was established as the normal life span for an incandescent lamp.

[2] *Efficacy - In lighting design, "efficacy" refers to the amount of light produced by a lamp (a light bulb or other light source), usually measured in lumens, as a ratio of the amount of power consumed to produce it, usually measured in watts.*

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This white paper was prepared by Electric Power Research Insitute (EPRI).

This 1,000 hour lamp life for incandescent bulbs is one of the primary areas that other lamp technologies have challenged in the marketplace as a weakness of incandescents. Manufacturers producing competing lighting technologies have advertised up to 30 times the life of incandescents to gain market share, but it must be noted that many extended lamp life claims are based on mathematical models or compressed life cycle testing. As a result, competing lamp technologies may or may not exceed the life span of an incandescent due to operating environment, operational conditions, physical characteristics, or thermal properties when operated in real world situations with real world power events. Additionally, lamps based on these other technologies are noticeably more expensive than the incandescent lamp. Consumers should evaluate all the characteristics of a lamp – lumen output, wattage consumed, color temperature, life span, operational conditions, and cost – to properly determine if that lamp technology is appropriate to operate satisfactorily in the desired application.

Energy Independence and Security Act - Incandescent Lighting Ramifications

The Energy Independence and Security Act (EISA) was passed in 2007 to address the inefficient energy consumption of various targeted technologies such as traditional incandescent lamps, carbon fuel based vehicles and certain commercial / industrial building systems. These technology areas were selected due to their overall percentage of national energy consumption, and the desire to flatten, or reduce, current national energy usage and future energy consumption levels. This bill has components which are being phased in over several years to allow consumers, manufacturers, distributors, and technology installers to transition away from older technologies to newer and more energy efficient technologies. New energy profiles, mandated under EISA, will be met through introduction of new products / designs, improvements to existing technologies, or elimination of the older technology to provide a path for future energy security.

In 2012, EISA requires that a 100-watt equivalent lamp must consume 72 watts or less. The EISA law allows a 100-watt equivalent lamp to produce between 1490 and 2600 lumens. Based on this range, an EISA-compliant *full spectrum* 100-watt equivalent lamp can range between 20.7 and 36.1 lumens per watt (20.7 lumens per watt = 1490 lumens / 72 watts; 36.1 lumens per watt = 2600 lumens / 72 watts). When compared to a traditional incandescent lamp (approximately 17 lumens per watt), these new lamps will offer an improvement in efficacy.

Dimmability, which is an important aspect for many residential consumers, has been a key issue that many compact fluorescent lamp (CFL) and light-emitting diode (LED) based products have had trouble addressing. This is because most CFL and LED dimmable products work best with new electronic dimmers. The added cost of a new dimmer, added cost of a compliant lamp or the unknown / unreliable performance of many CFL's and LED's with traditional dimmers has soured many end-users towards use of these products. In addition, some negative early customer experiences related to cost, lamp life and performance by both CFL's and LED's have resulted in many consumers refusing to consider these technologies for their lighting applications.

Several factors led lamp manufacturers to work toward the creation a second generation incandescent lamp. Some of the larger factors were: the passage of EISA 2007 and the energy criteria mandated within it; the increased development, product offerings, and marketing of CFL and LED based lamps; and the introduction of reduced carbon halogen products to the marketplace. To properly deal with those factors, and to meet the demands of the marketplace as well, lamp manufacturers knew the resulting next-generation incandescent lamp had to retain the shape of the traditional lamp, deliver dimmability via traditional dimmers, demonstrate a high color rendering index (CRI), have native 2700K correlated color temperature (CCT), and be compliment with all existing requirements of US law.

Advanced Lighting Technology - 2X Incandescent

Recently, due to consumer needs outlined above, one manufacturing company has developed a true 2X, or double efficiency, incandescent lamp. This lamp not only meets the requirements of EISA, as many other product offerings widely available in the marketplace from a variety of manufacturers, but one which offers a true step forward in the evolution of the incandescent lamp. This second generation 2X incandescent technology consumes approximately half the power of a traditional 100 W incandescent lamp, while still producing the same lumen output (roughly 1700 lumens for 100 W equivalent) and retaining the shape, dimmability, CRI, and CCT of a traditional incandescent.

Table 1. 2X Incandescent Lighting Performance and Energy Savings

Base Technology	EISA	2X	CFL / LED	Energy Saved of 2X Lamp Over Base, EISA, and CFL / LED Lamps
100W	72W	50W	23W	50W / 22W/ -27W
Base Efficacy	**EISA Efficacy**	**2x Efficacy**	**CFL / LED Efficacy**	**Standard Light Output for 100 W**
16.0 lm/W	22.2 lm/W	32.0 lm/W	69.5 lm/W	1600 lm

At the time of this study, final market pricing for the 2X incandescent was not available, but based on several industry assessments and the U.S. EPA's Report on *"Opportunities to Advance Efficient Lighting"* (October 2011), these lamps have the potential for significant consumer adoption as they will work in any fixture that currently supports the standard incandescent.

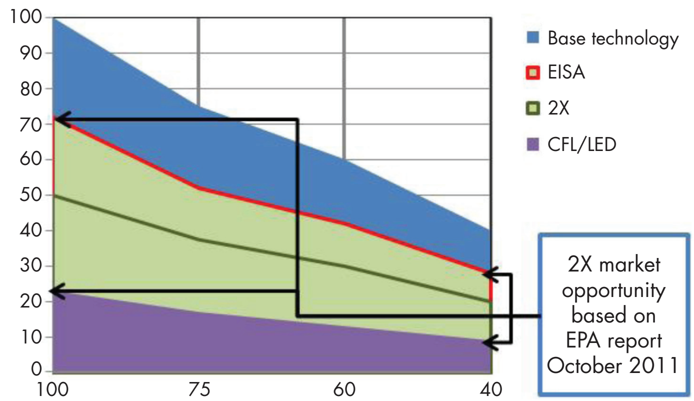

Figure 1. 2X Market Opportunity Graph

EPRI TEST PROCEDURE

With over 40 years of R&D experience, EPRI has developed expertise in consumer end-use equipment and its interaction with the national power grid. As a result of this prior research experience, EPRI employs a comprehensive approach to evaluate "system compatibility" in examining a product's impact on the power grid. As part of this process, EPRI's Lighting Laboratory has formed a series of categories in which to test a lighting product's performance. The four main categories include the product's energy consumption, photometrics, emissions, and immunity data. The ***energy consumption*** data includes the wattage and amperage that the product draws, as well as other relevant electrical data. The ***photometrics*** of a lighting product include its light output, color temperature, CRI and other data pertaining to the quality of light it produces. This data is important as it is the information that declares how well the product will fulfill its intended purpose. The ***emissions*** testing indicates what the product will introduce into its environment. This includes both radiated and conductive emissions. The latter being changes to the power quality on the input line and the former being all other forms of energy the product produces. The final set of testing, ***immunity***, is used to determine how the product will react to non-standard changes in its environment, such as a change in power quality. This includes whether the product will survive a power surge, or if it will fail under other conditions.

EPRI's system compatibility testing approach for the 2X incandescent lamps is outlined in Table 2 below. This methodology employed the four key aspects outlined earlier - energy consumption, photometrics, emissions, and immunity. As emissions were not as significant to this investigation, the emission tests were included as part of the photometric evaluations.

Table 2. EPRI Energy Efficiency and Compatibility Test Protocol for the 2X Incandescent Lamp Technologies

Phase I – Energy Performance Testing
Test 0. Initial Characterization
Test 1. Nominal Operating Conditions
Test 2. Partial-Load (Dimming) Test
Test 3. Response to Low Steady-State Input Voltage
Test 4. Response to High Steady-State Input Voltage
Phase I – Photometric Testing
Test 5. Lumen Output Performance
Test 6. Color Performance
Test 7A. Ultraviolet Performance
Test 7B. Infrared Performance
Phase I – Immunity Testing
Test 8. Susceptibility to Voltage Distortion
Test 9. Susceptibility to Voltage Sags
Test 10. Susceptibility to Voltage Swells
Test 11. Susceptibility to Voltage Fluctuations (Flicker)
Test 12. Electrical Fast Transient (EFT) Burst Test
Test 13. 0.5-μs, 100-kHz Ring Wave Surge Test
Test 14. 1.2/50-μs, 8/20-μs Combination Wave Surge Test
Phase II – Reliability Tests
Test 15. Extended Life Tests

Photometric Testing Parameters

A lamp's photometrics are defined by the quality of light produced. Light quality includes several different measurements: the lumen output3 which is the amount of light the lamp produces, and the correlated color temperature (CCT) which defines the shade of white the lamp produces. Traditionally the incandescent lamp has produced a CCT of approximately 2700K (although they can be purchased in a variety of temperatures today). As illustrated by Figure 2 below, the traditional 2700K temperature is in the yellow range and is closer to the color temperature of candlelight (approximately 1500-1800K), than it is to the color temperature of natural sunlight (approximately 5500K). Whiter or bluer lamps have a higher color temperature, and are more prevalent in the market today.

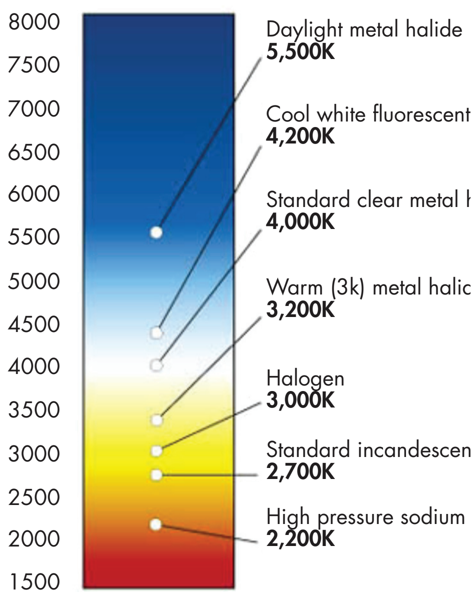

Figure 2. Color Temperature Chart – From Venture Lighting's Website - http://www.venturelighting.com/techcenter/lamps/color_of_light.htm

The Color Rendering Index (CRI) is a measurement of how individual colors appear under a light source. This value equates to the ability to see specific colors or shades of color on a surface or object when lit by a specific source. With a rating of 100, incandescent lighting typically provides the highest possible CRI of any lighting technology. This high CRI provides the consumer with a light source that is compatible with a variety of tasks – including reading, writing, office tasks, assembly, and manufacturing.

Emission testing quantifies the radiation emitted by the lamp, including visible light, infrared (IR) radiation and ultraviolet (UV) radiation. Though the ratio varies slightly from lamp to lamp, the design of a standard incandescent bulb allows 90 % of the power consumed by the lamp to be lost as heat, infrared, or ultraviolet and only 10 % of the power consumed to generate visible light.

EPRI TEST RESULTS: 2X INCANDESCENT LIGHTING

Energy and Photometric Performance Testing

Voltage Variations Testing

The lamps were placed within an integrating sphere and data regarding lumen output, color temperature (CCT), and color rendering index (CRI) was recorded. Data was also taken on the input line to the lamp to determine power quality and usage. After getting nominal data, three tests were performed. The first test monitored and recorded the lamp parameters as the lamp was dimmed using a standard 600-watt rotary dimmer. The other two tests maintained an over- or undervoltage condition at 10 % above (132 Vrms) or below (108 Vrms) nominal respectively.

Results: *As seen in Table 3 under normal conditions (steady 120 Vac) the 2X performed very similarly to a standard incandescent. During the low and high steady-state input voltage testing, the color temperature varied less than 200 K; remaining in the 2700 K – 3000 K range which is the established normal for incandescents. CRI stayed above 97.6 during the voltage fluctuations (keeping close to the standard 100 CRI of a normal incandescent). Also, during the dimming test, the 2X incandescent's lumen output, efficacy and color temperature all declined linearly with dimming, similar to the standard incandescent.*

Table 3. Comparison of Average Input Values and Photometric Values – Undervoltage and Overvoltage

Comparison of Average Input Values and Photometric Values – Undervoltage and Overvoltage						
Voltage	Current (mA)	Input Power (W)	Lumens	Color Temp (K)	CRI	Efficacy
108 V	400.9	44.48	1208	2791	98.12	27.16
120 V	436.2	52.41	1696	2925	97.89	32.36
132 V	458.9	60.56	2346	2988	97.80	38.74

[3] *One lumen is the amount of light a single candle can produce.*

Radiance Testing

Three 2X incandescent lamps and one standard 100 watt lamp were measured for their UV and IR radiation after being allowed to warm up and stabilize for thirty minutes. The results of the testing are summarized below in Table 4.

Results: *All four lamps produced so little UV radiation that even when the detector was placed directly on the lamp's surface there was a reading of 0. From thermal images in Figure 3 it was apparent that the temperature of the 2X incandescent (240°F) is about 60°F lower (a factor of over 25 %) than the standard incandescent (303°F). This can be attributed to the fact that the 2X lamp used nearly half the wattage, but also that the infrared radiation produced by the lamp package is actually less than the standard 100 watt incandescent.*

Table 4. Summary of Infrared and Ultraviolet Testing

Emissions Type	2x Incandescent	Standard Incandescent
Infrared (IR)	240°F	303°F
Ultraviolet (UV)	~0	~0

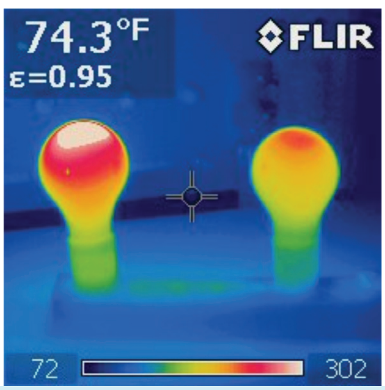

Figure 3. Thermal Image of a 100 Watt Incandescent (Left) and a 2X Incandescent (Right)

Immunity Testing

The lamps were subjected to several trials designed to test their immunity to significant changes in input voltages. These tests included voltage distortion, voltage sags, voltage swells, voltage flicker, electrical fast transients (EFT), and two types of voltage surges.

- **Voltage distortion** is caused by the interaction of non-linear loads with the impedance of the power system with levels in the range of 1 to 10 %. Higher levels of voltage distortion may be created by the magnification of harmonic currents by resonance conditions on the power system.
- **Voltage sags** in the line voltage lasting for several cycles or longer may result during power system faults or when heavy customer loads are switched on. These disturbances may produce unpredictable results for voltage-sensitive equipment on the line and are common, direct causes of electronic-system upsets.
- **Voltage swells** characterize the ability of the lamp to withstand a sustained high voltage event. If a swell results in extinguishing the lamp or deformation of the filament, then they can be used to characterize the changes in lamp operation after a swell.
- **Voltage fluctuations** (flickering) are as a function of the degree of typical line-induced voltage fluctuations injected into the voltage input.
- **Electrical fast transients** (EFT Burst Wave) is defined as having a 5-nsec rise time and a 50-nsec duration. Individual pulses occur in bursts with durations of 15 msec. The maximum voltage level of the EFT Burst in this test is targeted at a maximum of 4 kV.
- **Ring waves** are the most frequently observed transient overvoltages occurring in low-voltage power systems for all types of service entrances. They can damage or deform an incandescent lamp's filament.
- **High energy surges** such as those caused by lightning and high-voltage switching are known to exist in low-voltage systems and can cause failure of electrical and electronic loads. The combination wave, which is a simultaneous open circuit voltage wave form and a short circuit current waveform, has long been used to represent low-voltage surges caused by lightning on overhead lines.

Results: *In order to have passed any of the above tests, a lamp must have remained lit, undeterred by voltage fluctuations. Table 5 summarizes the results confirming that the 2X lamp performed similarly to the 100 watt incandescent.*

Table 5. Results Summary of Immunity Testing of the 2X Incandescent Lamp

Immunity Test	2X Incandescent	Stdandard Incandescent
Susceptibility to Voltage Distortion	✓	✓
Susceptibility to Voltage Sags	✓	✓
Susceptibility to Voltage Swells	✓	✓
Susceptibility to Voltage Fluctuations (Flickering)	✓	✓
Electrical Fast Transient Burst Test (Up to 4kV)	✓	✓
Ring Wave Surge Test (Up to 6kV)	✓	✓*
Combination Wave Surge Test (Up to 6kV)	✓	✓*

**Typically an incandescent lamp will not survive a direct surge during testing, but there are some exceptions*

Extended Life Testing

As a final test, the lamps were subjected to the extended life testing in which the 2X incandescent lamps were wired to a timer and put on a cycle of on for three hours and off for one. This was to compare the typical lifetime of a 100 watt incandescent lamp (1000 hours) to the life of the 2X incandescent.

Results: *At 1000 hours, none of the 2X lamps had failed – all passed the test and lasted longer than the requirement for standard incandescent lamps. At 1500 hours, only three of the tested lamps had failed. 70% of the test samples exceeded 2000 hours of operation prior to failure with 50% of the lamps reaching 2400 hours and beyond.*

CONCLUSION

The tested 2X incandescent lamp is a true 100 watt incandescent equivalent with respect to all output / performance values, lifespan, and only consumes roughly half the input power.

A thorough investigation of the 2X incandescent lamp revealed that the lamp performs similarly to the standard 100 watt incandescent in nearly all aspects of power, photometric performance, and lifespan (exceeding original specifications). In the areas of power consumption and generated heat there are some notable improvements between the evaluated product and the traditional 100 watt incandescent.

Table 6 shows a comparison between the 2X incandescent and a standard 100 watt incandescent.

Table 6. Comparison of Average Input Values and Photometric Values of 2X and Standard 100 Watt Incandescent

Comparison of Average Input Values and Photometric Values						
	Input Power (W)	Lumens	Color Temp (K)	CRI	Efficacy	Infrared Radiation (Thermal)
2X Incandescent	52.41	1696	2925	97.89	32.36	240°F
100 Watt Incandescent	100	1700	2700 - 3000	100	17	303°F
Difference	-47.59	-4	n/a	-2.11	+15.36	-63°F

From this table, one can easily see that the output of the 2X incandescent is very close to that of the standard 100 watt incandescent in most categories. As noted above, the major difference between the 2X technology and the traditional incandescent occurs on the input side of the lamp. The 2X incandescent draws nearly half (52.41 watts) the power of the standard 100W incandescent while still producing approximately the same light output (1696 lumens), color temperature (2925 K), and CRI (97.89). The efficacy is improved over a standard 100 watt incandescent by 15.36 lumens per watt on average. Due to its use of less power and lower infrared emissions, the lamp runs about 63 degrees Fahrenheit cooler than standard incandescent lamps.

Since these 2X lamps were tested prior to the manufacturer's retail sale of the product, a market price analysis of this technology was not performed as part of this study. Based on several industry assessments and the U.S. EPA's Report on *"Opportunities to Advanced Efficient Lighting"* (October 2011), these lamps have the potential for significant consumer adoption as they will work in any fixture that currently supports the standard incandescent. Future analysis of the total cost of ownership, installation, and value comparing this technology to competing technologies would further benefit the industry.

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