Appliance Standards Awareness Project
Natural Resources Defense Council
Alliance to Save Energy
American Council for an Energy-Efficient Economy
National Consumer Law Center
Northeast Energy Efficiency Partnerships
Northwest Energy Efficiency Alliance

November 28, 2011

Ms. Brenda Edwards
U.S. Department of Energy
Building Technologies Program
1000 Independence Avenue, SW
Mailstop EE-2J
Washington, DC 20585

RE: Docket Number EERE–2011–BT–STD–0006/ RIN 1904–AC43: Framework Document for General Service Fluorescent Lamps and Incandescent Reflector Lamps

Dear Ms. Edwards:

This letter constitutes the comments of the Appliance Standards Awareness Project (ASAP), Natural Resources Defense Council (NRDC), Alliance to Save Energy (ASE), American Council for an Energy-Efficient Economy (ACEEE), National Consumer Law Center (NCLC), Northeast Energy Efficiency Partnerships (NEEP), and Northwest Energy Efficiency Alliance (NEEA) in response to the notice of public meeting and availability of the framework document for energy conservation standards for general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs). 76 Fed. Reg. 56678. We appreciate the opportunity to provide input to the Department.

We encourage DOE to pursue the development of a new metric for reflector lamps. The current metric measures efficacy based on the total light output from the lamp. Since reflector lamps are directional lamps intended to focus light in a beam, a more appropriate metric would measure efficacy based on the light provided in a beam. A new metric focused on efficacy within a beam would better represent reflector lamp efficiency and would provide better information to consumers about the useful light provided by reflector lamps. At the public meeting on October 4, 2011, NEMA indicated that it is in the early stages of discussing a new metric for reflector lamps and that it intends to work with DOE on this effort. We are pleased that NEMA plans to work on developing a new metric, and we encourage DOE to work with NEMA on this effort. However, we also encourage DOE to pursue work on a new IRL metric and test procedures in parallel to NEMA's efforts to help advance the process. We understand that DOE is currently conducting testing on both refrigerator ice makers and residential water heaters in support of test procedure development for both products. At the same time, AHAM is working on developing a test procedure for ice makers, and AHRI and ASHRAE are working on potential amendments to the residential water heater test procedure. We believe that this model of DOE working in parallel to industry on test procedures and a performance metric could be successfully applied to IRLs.

While ideally a new metric could be developed within a short timeframe so that the standards in the final rule could be based on the new metric, we recognize that this may not be feasible. However, we believe that it is important for DOE to pursue the development of a new metric for IRLs in the near term regardless of whether the metric can be finalized in time for the 2014 standards final rule. Amended standards will likely go into effect in 2017, which means that the effective date of the subsequent round of standards may not be before 2025. Therefore, DOE should not delay the development of a new metric until the subsequent standards rulemaking. Even if a new metric is not developed in time for the 2014 final rule, a new metric finalized in the near term can be utilized in at least two ways: (1) A new metric could be used by ENERGY STAR and other voluntary programs to better distinguish high-performance reflector lamps; and (2) If the test procedure is amended, EPCA directs the Secretary to amend the standards based on the average performance of minimally compliant products as measured by the amended test procedure. 42 U.S.C. § 6293(e)(2). This would allow a new test procedure based on a new metric to be utilized to determine compliance with the standards before the effective date of the next round of standards.

The scope of this rulemaking should include the ER, BR, and small diameter IRLs that are currently exempt from standards. The framework document states that because DOE is currently conducting a separate rulemaking for these ER, BR, and small diameter IRLs, the Department is not considering amending standards for these lamps as part of the GSFL and IRL rulemaking. We are pleased that DOE has correctly concluded that it has the authority to adopt standards for these lamps and that the Department is currently conducting a rulemaking to establish initial standards. However, we believe that it is important that all reflector lamps be subject to standards of similar stringency so as not to continue the problem of reflector lamp market distortions. Currently, the ER, BR, and small diameter lamps that are exempt from standards represent a significant loophole in the IRL standards. We encourage DOE to complete the rulemaking for these ER, BR, and small diameter lamps as soon as possible to close this loophole. We also urge DOE to include these lamps in the rulemaking on GSFLs and IRLs so that by 2017 all reflector lamps must meet the same standard levels. In addition to the benefits of syncing the standard levels for all IRLs, we believe that there is significant opportunity for efficiency improvements for IRLs beyond the efficiency levels prescribed in the 2009 Lamps Rule, as we discuss below. Since the exempt ER, BR, and small diameter lamps represent a substantial portion of the IRL market, including these lamps in the GSFL and IRL rulemaking could yield significant additional energy savings.

We recognize that setting standards now for these exempt IRLs and also including these lamps in the GSFL and IRL rulemaking would mean that these lamps could be subject to different standards with effective dates only a few years apart. If DOE completes the rulemaking for the exempt ER, BR, and small diameter IRLs in 2012, the standards would likely go into effect in 2015. With a final rule in 2014, the standards in the GSFL and IRL rulemaking would then go into effect in 2017. We believe that this sequence of effective dates for the ER, BR, and small diameter IRLs is feasible. However, if DOE determines that effective dates of 2015 and 2017 for these lamps would not be feasible, we believe that it is still important to include the ER, BR, and small diameter lamps in the GSFL and IRL rulemaking even if these lamps are subject to a slightly later effective date than that of other IRLs.

We encourage DOE to consider establishing standards for additional types of fluorescent lamps with significant potential energy savings. The framework document states that DOE is considering adopting standards for pin-based compact fluorescent lamps (CFLs), non-linear fluorescent lamps, and fluorescent lamps with alternate lengths. We encourage DOE to evaluate whether there are significant potential energy savings associated with these lamp types to justify national standards. With respect to fluorescent lamps with alternate lengths, we encourage DOE to consider establishing standards for linear fluorescent lamps that apply to lamps within a range of lamp lengths. The current standards for GSFLs only apply to 4-foot and 8-foot lamps and 2-foot U-shaped lamps. Since simply modifying lamp length slightly would now exempt a lamp from standards, a standard that applies to fluorescent lamps of any length (within a range) would help prevent any potential loopholes.

DOE must consider higher efficiency levels for IRLs. In the framework document, DOE presents only one candidate standard level (CSL) level for IRLs, which is identical to the highest efficiency level evaluated for the 2009 Lamps Rule. As the California IOUs explain in their comments, DOE has not identified the maximum technologically feasible level for IRLs. As part of the analysis for amended standards, DOE must consider both the most efficient commercially-available IRLs as well as working prototypes. Research conducted by Ecos in 2009 for Pacific Gas and Electric Company, NRDC, and ASAP (attached) found that the combination of a highly efficient double-ended halogen capsule with an advanced IR coating and a silverized reflector yields efficiency levels 59% higher than the efficacy level in TSL 5 in the 2009 Lamps Rule. Given the high annual shipment volumes of IRLs and the significant potential efficacy improvements, which are outlined in the CA IOU comments, we believe that higher efficiency levels for IRLs represent a large national energy savings opportunity.

DOE should reevaluate the efficacy reduction for modified spectrum IRLs. We believe that the current efficacy allowance of 15% for modified spectrum IRLs is too large and could potentially result in modified spectrum lamps becoming a low-cost option in the market and therefore a significant potential loophole in the standards. The research conducted by Ecos described in the attached report found that an average light loss of 9-11% is sufficient to modify a lamp's spectrum such that it meets the 4 MacAdam step minimum as specified in the EISA 2007 definition of "modified spectrum." The Ecos research also found that it is feasible to make modified spectrum IRLs that greatly exceed the TSL 5 efficacy level in the 2009 Lamps Rule for *clear* lamps. Ecos tested lamp assemblies with modified spectrum lenses that exceed TSL 5 for *clear* lamps by 35-49%. Therefore, we urge DOE to either remove the allowance for modified spectrum IRLs or to lower the allowance to <10%.

Thank you for considering these comments.

Sincerely,

Andrew deLaski
Executive Director
Appliance Standards Awareness Project

Noah D. Horowitz
Sr. Scientist
Natural Resources Defense Council

Jeff Harris
Vice President for Programs
Alliance to Save Energy

Jennifer Amann
Director, Buildings Program
American Council for an Energy-Efficient Economy

Charles Harak, Esq.
National Consumer Law Center
(On behalf of its low-income clients)

Susan E. Coakley
Executive Director
Northeast Energy Efficiency Partnerships

Charlie Stephens
Sr. Energy Codes & Standards Engineer
Northwest Energy Efficiency Alliance

Energy Conservation Standards for General Service Fluorescent Lamps and Incandescent Reflector Lamps – Notice of Proposed Rulemaking (NOPR)

Title:

Optical Losses of Modified Spectrum Lenses on Incandescent Reflector Lamps

Prepared for:

Pacific Gas and Electric Company

Natural Resources Defense Council

Appliance Standards Awareness Project

Prepared by:

Ecos

1199 Main Avenue, #242

Durango, CO 81301

970 259-6801

Last Modified: May 20, 2009

Table of Contents

This report was prepared in part by Pacific Gas and Electric Company and funded in part by the California utility customers under the auspices of the California Public Utilities Commission.

Introduction

In March and April of 2009, Ecos conducted research on modified spectrum incandescent reflector lamps (IRL) for Energy Solutions on the behalf of the Pacific Gas & Electric Company (PG&E), the Natural Resources Defense Council (NRDC), and the Appliance Standards Awareness Project (ASAP). The purpose of this research project is to determine if DOE should allow modified spectrum incandescent reflector lamps (IRLs) to comply with a less stringent standard than it proposes for conventional IRLs and, if so, what that percentage allowance should be. In preparation for this rule-making, the DOE conducted limited testing of commercially available modified spectrum IRLs. Based on their findings, the DOE recommended that IRL standards allow modified spectrum lamps to be 19% dimmer and less efficient than non-modified spectrum lamps. PG&E, NRDC, and ASAP contracted with Ecos in order to confirm the U.S. Department of Energy (DOE) findings or to recommend a different allowable light output reduction for modified spectrum lamps.

In the report that follows, we provide an overview of the DOE's research and recommendations, discuss our research methodologies and findings, and provide recommendations on the light output reduction that modified spectrum IRLs should be permitted in the pending federal efficiency standard for IRLs. Please note that this report has been updated slightly from the version submitted on May 13, 2009 (See Footnote 5).

Modified Spectrum Lamps

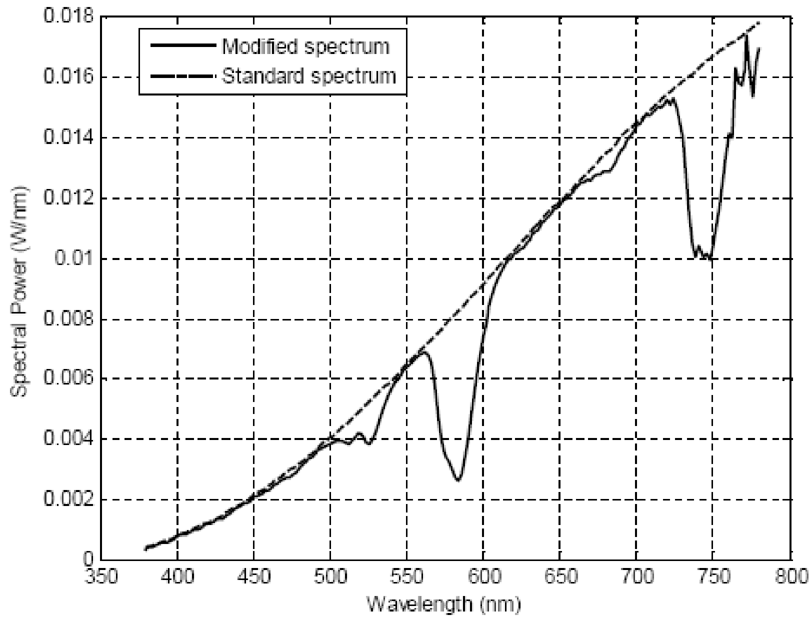
According to the IESNA[1], modified spectrum lamps, also known as "daylight" lamps, have "bluish glass bulbs that absorb some of the long wavelengths produced by the filament. The transmitted light is of a higher correlated color temperature….This [color temperature] is almost midway between tungsten filament light and daylight" (p. 6-7). Marketing claims about modified spectrum lamps state that they "filter out dull yellow light," "produce clean, beautiful light,"[2] and produce "a whiter, more natural light that makes any room look its best"[3] . Modified spectrum lamps are marketed under many names, including "Reveal," "natural light," "daylight," and "full spectrum." In order to achieve the color effect of a modified spectrum lamp, portions of yellow, green and red wavelengths are removed from the spectrum of a standard incandescent lamp (see spectral distribution diagram below from DOE's standards analysis, page 5C-2). The smooth arc is produced by a standard incandescent reflector lamp; the curve with valleys around 580 nm and 740 nm was produced by a modified spectrum IRL. These valleys represent areas of the spectrum where the modified spectrum bulb covers filter out visible light.

[1] Rea, Mark S., ed., *The IESNA Lighting Handbook: Reference & Application, Ninth Edition.* 2000. The Illuminating Engineering Society of America: New York, New York.

[2] Source: GE website, http://www.gelighting.com/na/home_lighting/products/reveal_main.htm

[3] Source: Description of Sylvania's "Full Spectrum" products, http://www.genesislamp.com/fusplibu.html

Figure 1. Spectral Power Distributions of Modified Spectrum and Standard Spectrum Lamps



The modified spectrum effect is often created by using neodymium oxide in the glass bulb enclosure. Other types of coatings and techniques can also be used to absorb portions of the yellow, green and red wavelengths in the visible spectrum. Because, in incandescent technology, the modified spectrum effect is achieved only through filtering out portions of the spectrum, the lamp's overall efficacy is reduced.

The proposed DOE IRL standards use the following definition of modified spectrum that is referenced in the Energy Independence and Security Act of 2007 (EISA 2007). (See EISA 2007 page H.R. 6—84):

> ''(W) MODIFIED SPECTRUM.—The term 'modified spectrum' means, with respect to an incandescent lamp, an incandescent lamp that—
> > ''(i) is not a colored incandescent lamp; and
> > ''(ii) when operated at the rated voltage and wattage of the incandescent lamp—
> > > ''(I) has a color point with (x,y) chromaticity coordinates on the Commission Internationale de l'Eclairage (C.I.E.) 1931 chromaticity diagram that lies below the black-body locus; and
> > > ''(II) has a color point with (x,y) chromaticity coordinates on the C.I.E. 1931 chromaticity diagram that lies at least 4 MacAdam steps (as referenced in IESNA LM16) distant from the color point of a clear lamp with the same filament and bulb shape, operated at the same rated voltage and wattage.

In EISA, a colored lamp is defined as follows (see page H.R. 6—85):

> ''(EE) COLORED INCANDESCENT LAMP.—The term 'colored incandescent lamp' means an incandescent lamp designated and marketed as a colored lamp that has—
> H. R. 6—86

> ‘‘(i) a color rendering index of less than 50, as determined according to the test method given in C.I.E. publication 13.3–1995; or
> ‘‘(ii) a correlated color temperature of less than 2,500K, or greater than 4,600K, where correlated temperature is computed according to the Journal of Optical Society of America, Vol. 58, pages 1528–1595 (1986).’’.

Throughout the rest of this document, this definition of modified spectrum will be referred to as the *EISA 2007* definition of modified spectrum.

Department of Energy (DOE) IRL Background

To better understand the optical losses associated with modified spectrum IRLs, the DOE conducted research using commercially available standard and modified spectrum IRLs.

> In total, DOE purchased eight pairs of parabolic aluminized reflector (PAR) lamps. Seven pairs consisted of halogen lamps, and one pair consisted of halogen infrared (HIR) lamps. Each pair contained three samples of an IRL model advertised as modified-spectrum along with three samples of a corresponding standard-spectrum IRL model in the same product line. Halogen and HIR lamps were selected because the IRL design options that meet the proposed IRL standards in this rulemaking consist of both halogen and HIR technologies. U.S. DOE[4], p. 5C-7

DOE researchers then compared measured light output of the modified spectrum IRLs to their standard spectrum counterparts. They also compared the x,y color coordinates of each pair of lamps to determine if the color coordinates were located the minimum distance apart (four MacAdam steps) as required by the EISA 2007 definition of a modified spectrum lamp. Only two of the eight lamp pairs met the minimum four MacAdam step requirement for modified spectrum lamps. The modified spectrum IRLs from these two pairs had an average 19% light output reduction when compared to their standard spectrum counterpart. Therefore, the DOE recommended that IRL efficiency standards for modified spectrum IRLs allow a 19% reduction in light output. Throughout the rest of the report, the trial standard levels (TSL) that represent a 19% light output reduction for modified spectrum lamps will be referred to as *modified spectrum TSL* or *MS TSL*; TSLs for non-modified spectrum (clear) lamps will be referred to as *clear TSL*.

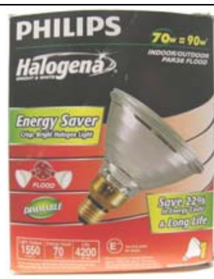
Research & Findings

For this research, we purchased a total of eleven models of PAR 38 clear and modified spectrum IRLs. We selected the same shape and size lamps so that we could exchange modified spectrum lenses for clear lenses to determine the effect on light output and color associated with modified spectrum lenses. The lamps we purchased represented the range of offerings available locally and online. We specifically sought out models that were likely to meet clear and modified spectrum TSL 4 or TSL 5, since these are the levels under consideration by the DOE. Additionally, Deposition Sciences, Inc. (DSI) supplied us with

[4] Source: U.S. Department of Energy, January 12,2009, Notice Of Proposed Rulemaking (NOPR) Technical Support Document (TSD): Energy Conservation Standards for General Service Fluorescent Lamps and Incandescent Reflector Lamps

two components for this research—a silverized reflector and an HIR burner rated at 1,500[5] hours. Both products are early production models and not yet incorporated into commercially available products; however, DSI expects these components to be incorporated into commercially available products shortly. We fitted the DSI burner to the DSI reflector in our lab. See photos of purchased lamps and DSI components below.

Table 1. Clear (Standard Spectrum) IRL Samples

			
GE HIR Plus Halogen Display Lamp CG381HIR60FL1	Philips Halogena 70PAR38/HES/FL25 818077	Sylvania Capsylite 75PAR38/CAP/SPL/FL30 N06220	Sylvania Capsylite 120PAR/CAP/SPL/FL30 N06314
Clear TSL 5	Clear TSL 4	< Clear TSL 1	< Clear TSL 1

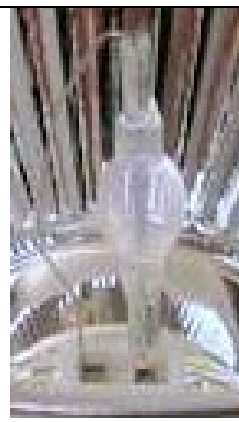
		
Philips Halogen PAR 60PAR38/FL25 814778	Sylvania Soft White 75PAR38/HAL/SW	Philips Natural Light Plus 75PAR38/NLP/FL 816268
Clear TSL 1	Clear TSL 2	< Clear TSL 1

[5] Please note that this version of the report has been updated since the original report was submitted on May 13. The report now accurately lists the life of the DSI burner at 1,500 hours, rather than 1,000 hours.

Table 2. Modified Spectrum IRL Samples

			
Sylvania Daylight 75PAR38/DAY/FL	Sylvania Daylight Plus 60PAR38/CAP/DAY/FL30	GE Reveal CG381RVL 81864	LiteTronics Xtreme-White 85WPAR38
MS TSL 2	MS TSL 2	MS TSL 2	< MS TSL 1

Figure 2. New Product Samples from Deposition Sciences

	
DSI Reflector (silverized) with DSI Burner (rated at 1,500 hours)	DSI Burner Close-up

We first seasoned (or burned in) all lamps for 100 hours according to IESNA Guide to Lamp Seasoning LM-54-99. We then tested all lamps in our SphereOptics integrating sphere to determine light output (lumens), lamp power (watts), correlated color temperature (CCT in degrees Kelvin), x & y color points, and color rendering index (CRI). We also recorded each lamp's spectral power distribution. Among clear IRLs, we found one commercially available model — the GE HIR Plus — that exceeded clear TSL 5 (for standard spectrum), and one model — the Philips Halogena Energy Saver — that met clear TSL 4. The rest of the clear lamps fell below the clear TSL 4 level.

We were able to purchase modified spectrum IRL samples for testing that utilized traditional tungsten filaments as well as halogen capsules, but were not able to purchase any halogen IR models. Therefore, we did not expect any of our modified spectrum sample to achieve clear TSL 4 or clear TSL 5. The modified spectrum lamps we tested met modified spectrum TSL 2 with one exception. The Halogen PAR 38 from Litetronics fell below the modified spectrum TSL 1 level. (Note that all modified spectrum levels allow lamps to be 19% dimmer than the corresponding clear TSL levels). Due to the marketing on the Philips Natural Light PAR 38, we expected this lamp to be a modified spectrum. In fact, when we tested it, its continuous spectral power distribution revealed that it was a standard spectrum lamp. The burner in this lamp had a bluish hue; the glass lens was clear.

Figure 3. Clear IRL Test Results Compared to Clear TSL Levels

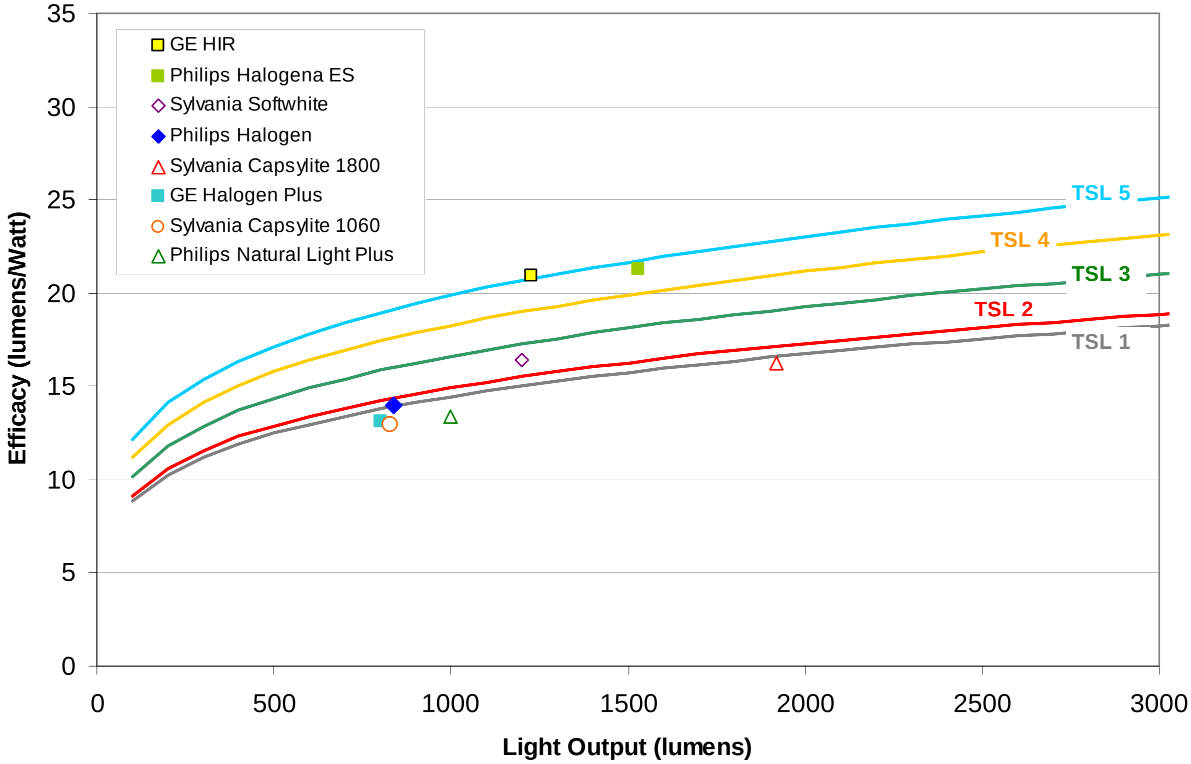
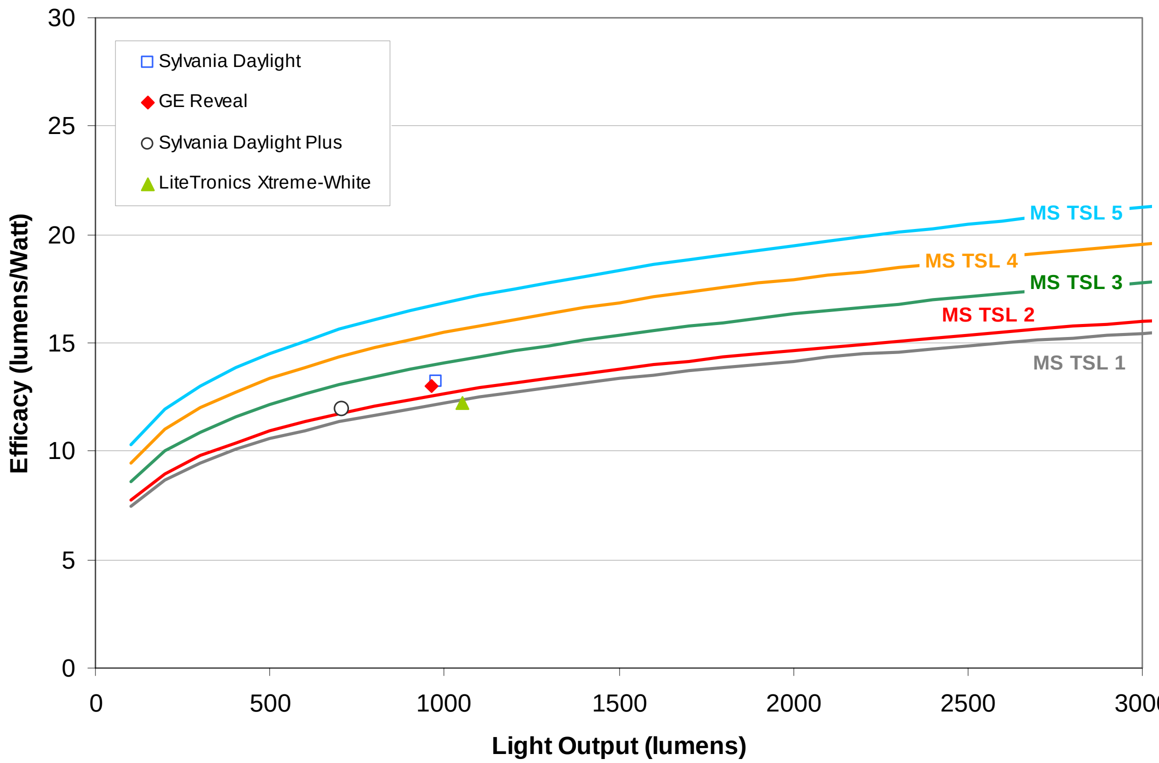
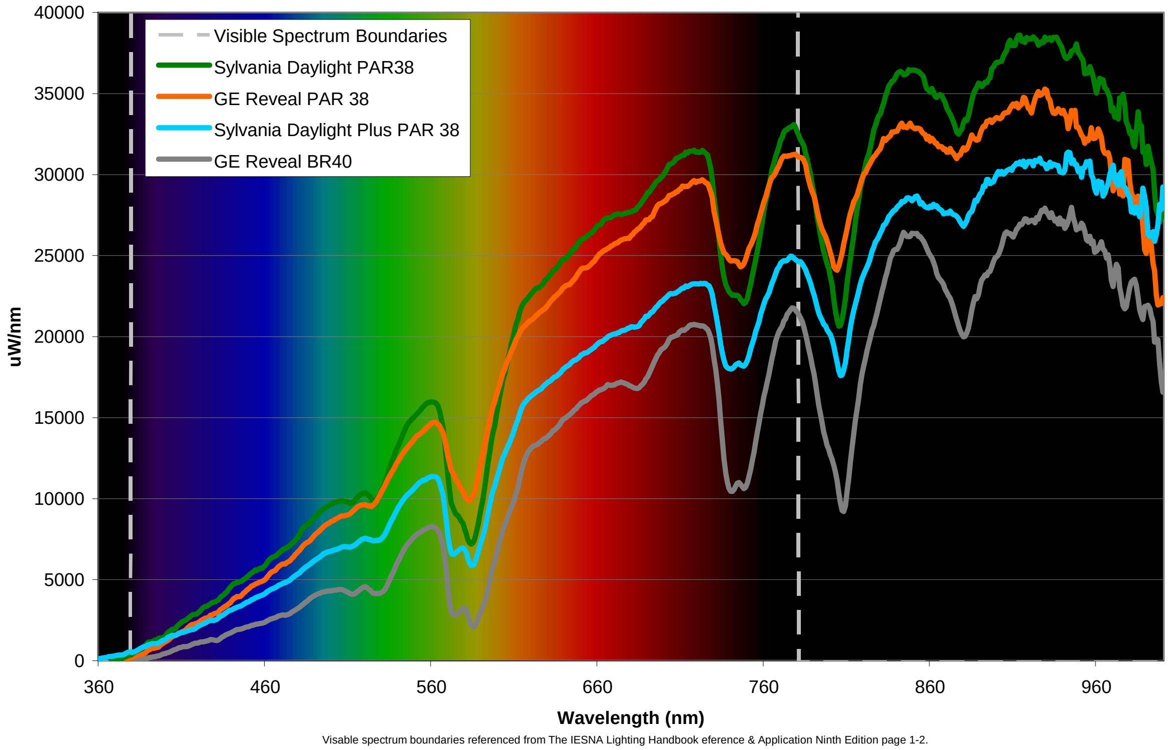


Figure 4. Modified Spectrum Lamp Test Results Compared to Modified Spectrum TSL Levels



We noticed a wide variation of light filtration levels among the modified spectrum samples. While all light filtration occurs in the same parts of the spectrum, lamps showed variances in the percentages of light filtered in the yellow/green and red areas of the spectrum. See the graph of modified spectrum spectral power distributions below. We tested the PAR 38 models for this research; all contain halogen capsule burners. The GE Reveal BR40 lamp is a traditional tungsten filament incandescent evaluated for previous research. Note how the light in the yellow/green and red areas of the spectrum is filtered out to a greater extent than in the PAR 38 lamps with halogen capsule burners. Also, note how the GE Reveal PAR 38 has the least light filtration in these same areas of the spectrum. These results suggest that several techniques for modifying a lamp's spectrum are used for different lamp models, and that modified spectrum lenses that filter out the least amount of light may be most appropriate for use with efficient burner technologies like HIR.

Figure 5. Spectral Power Distributions of Modified Spectrum IRLs



Once all lamps were tested, we removed the glass lenses from the GE HIR and Philips Halogena ES clear IRLs (the two most efficient reflector lamps tested). Next, we removed the modified spectrum lenses from the Sylvania Daylight, the Sylvania Daylight Plus, and the GE Reveal lamps. See photos below for images of lamps with lenses removed, and the lenses after removal.

Figure 6. IRLs with Lenses Removed

Figure 7. Modified Spectrum (left) and Clear (right) Lenses Removed from Lamps

Best Available Reflector & Burner Technology Testing

For the first round of testing, we connected the DSI silverized reflector sample to the DSI HIR burner sample. The combined reflector/burner assembly is pictured below.

Figure 8. Deposition Sciences Reflector and HIR Capsule Assembly

We then placed a clear lens on top of the reflector/burner assembly and measured the light output, CCT, CRI, spectral distribution, and x,y color points in the integrating sphere. Next, we measured the same reflector/burner assembly with the three modified spectrum lenses that we had removed from our modified spectrum IRL lamps. By comparing resulting measurements of the clear, base case IRL with the three modified spectrum assemblies, we were able to determine: 1) light loss caused by modified spectrum lenses, and 2) whether combinations of reflectors, burners, and modified spectrum lenses met the EISA 2007 definition of modified spectrum.

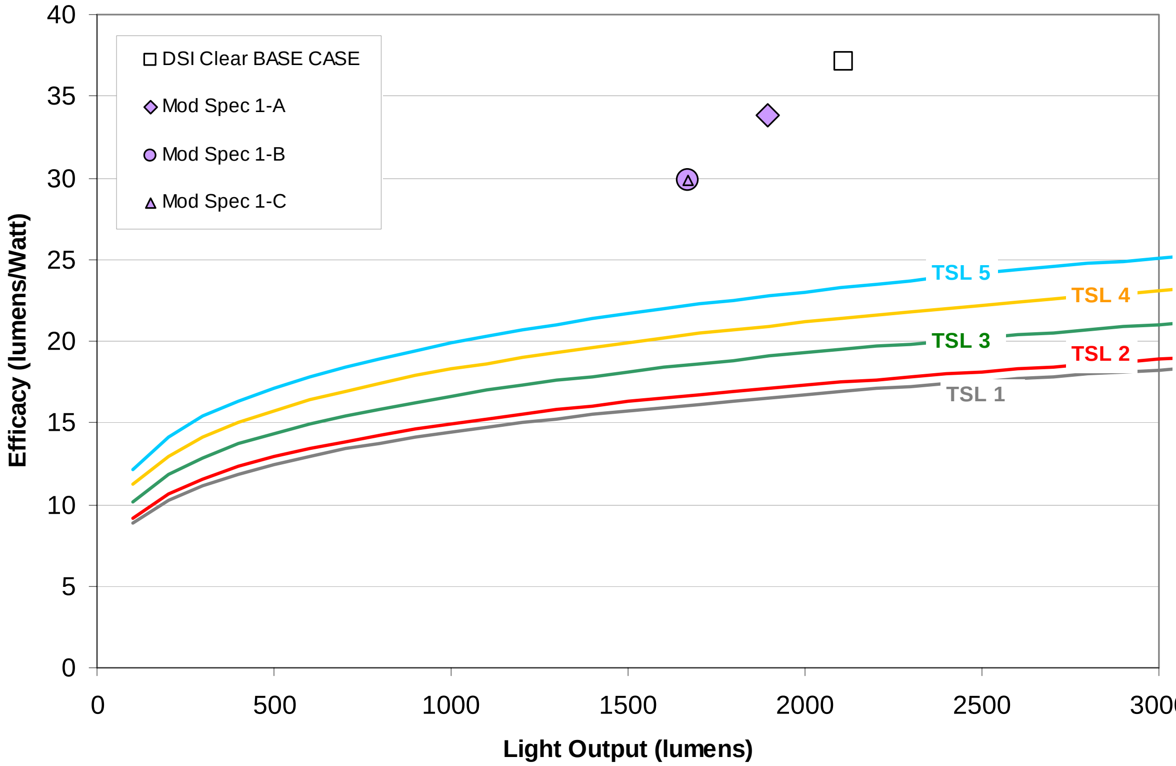
Figure 9. Lamp Assembly with Modified Spectrum Lens in Integrating Sphere

What we found is that the DSI reflector/burner assembly with a clear lens greatly exceeds clear TSL 5. When we exchanged the clear lens for the modified spectrum lenses, each modified spectrum lamp assembly still exceeded the clear TSL 5. In addition, all three modified spectrum assemblies met the EISA 2007 definition of “modified spectrum,” meaning that the x,y color point coordinates for each modified spectrum assembly were a minimum distance of four MacAdam steps away from the DSI clear lamp assembly, that the CCTs fell between 2,500K and 4,600K, and that the x,y coordinates fell below the black body locus. Both Sylvania modified spectrum lenses caused a light output reduction of 21% when compared to the assembly with the clear lens. The GE Reveal lens caused only a 10% light output reduction.

Table 3. Best Available Technology Clear & Modified Spectrum Assemblies

	Burner	Reflector	Lens Type	Lens Brand	MS TSL level	Clear TSL level	Lumens	Watts	lm/W	% Lumen Reduction from MS Lens	MacAdam Steps away from Base Case	Meets EISA 2007 Definition of Mod Spec?
Clear Base Case 1	HIR (DSI)	Silverized (DSI)	Clear	Philips Halogena ES	N/A	5	2110	57	37.1	N/A	N/A	N/A
Mod Spec 1-A	HIR (DSI)	Silverized (DSI)	Mod. Spec.	GE Reveal	5	5	1895	56	33.8	10%	4.4	Yes
Mod Spec 1-B	HIR (DSI)	Silverized (DSI)	Mod. Spec.	Sylvania Daylight	5	5	1671	56	29.8	21%	6.02	Yes
Mod Spec 1-C	HIR (DSI)	Silverized (DSI)	Mod. Spec.	Sylvania Daylight Plus	5	5	1672	56	29.9	21%	6.43	Yes

Figure 10. Best Available Technology Clear and Modified Spectrum Assemblies



Based on these results, we found that it is feasible to make modified spectrum incandescent reflector lamps that meet the EISA 2007definition for modified spectrum lamps while greatly exceeding clear TSL 5. The combination of the Deposition Sciences HIR burner, Deposition Sciences silverized reflector, and a clear lens exceeded clear TSL 5 by 59% at a light output of 2110 lumens. When this lamp assembly was re-tested with modified spectrum lenses instead of a clear lens, all three samples still exceeded clear TSL 5 for regular spectrum lamps by 35 to 49%. All met the EISA 2007 definition of modified spectrum.

Off-the-Shelf Reflector & Burner Technology

For the next phase of this research, we created combinations of off-the-shelf burners and reflectors with various lenses to determine the light loss associated with modified spectrum lenses matched to IRL lamp components on the market today. In order to keep our testing relevant to the proposed TSL 4 and 5 levels, we used various combinations of burners and reflectors from the only two standard spectrum IRLs that we tested that met clear TSL 4 or clear TSL 5—Philips Halogena Energy Saver (clear TSL 4) and GE HIR (clear TSL 5). We used the same Sylvania Daylight and GE Reveal modified spectrum lenses from the previous testing. (Because the Sylvania Daylight and Sylvania Daylight Plus lenses caused essentially the same optical effects in the previous round of testing, we used only the Sylvania Daylight lens in this round of testing.) Additionally, we experimented with multiple combinations of burners and reflectors to capture the widest range of results possible.

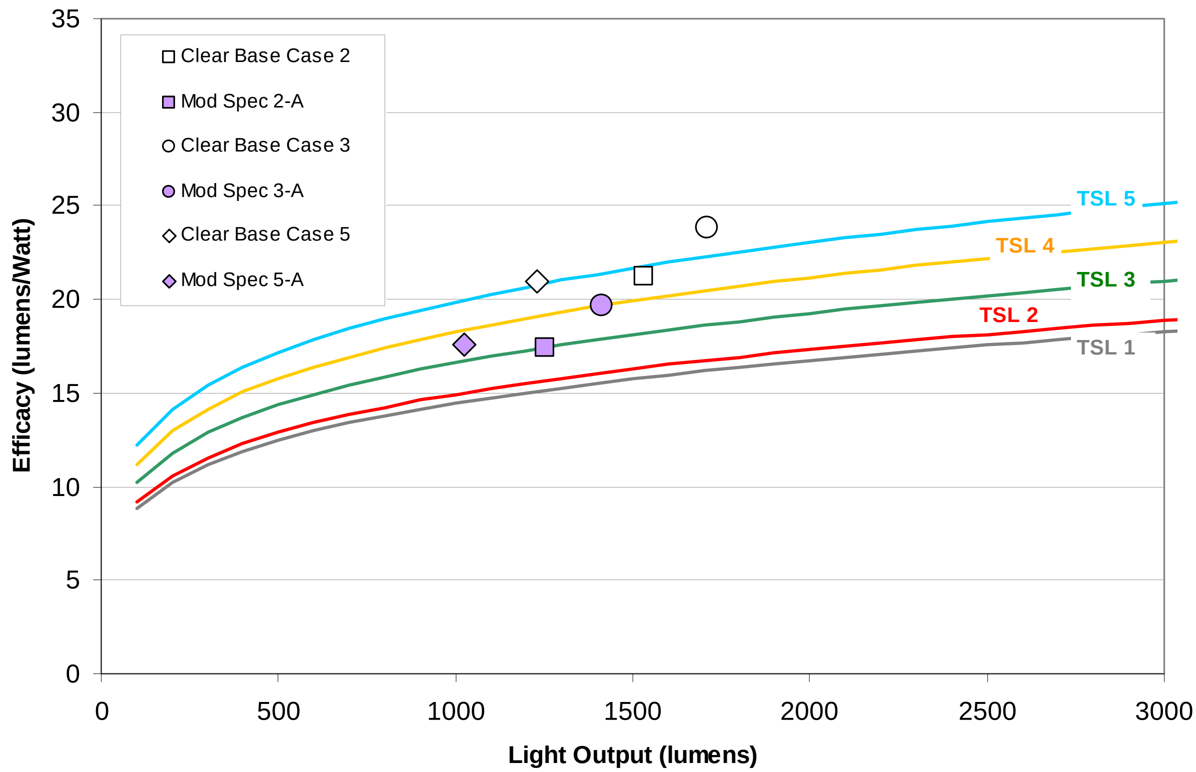
The GE Reveal modified spectrum lens typically caused light output reduction of <10%; however, off-the-shelf burner/reflector assemblies tested with this lens did not meet the EISA 2007definition of modified spectrum because the x,y color points were less than four MacAdam steps away from the clear base case assemblies. We can infer from this that the color properties of the base case DSI burner/reflector combination are slightly different from the color properties of the base case combinations from GE and Philips, such that a given modified spectrum lens results in different *relative* changes to color when used with them.

Lamp assemblies tested with the Sylvania Daylight modified spectrum lens all met the EISA 2007definition, yet this lens caused light losses of approximately 17%. These modified spectrum lamp assemblies tended to have a greater color shift (more than six MacAdam steps) than is required by the EISA 2007 definition of modified spectrum (more than four MacAdam steps).This suggested that less light loss could be achievable if manufacturers designed modified spectrum lenses to achieve a color shift closer to four, rather than six or seven MacAdam steps. Despite varying levels of color shift and light loss, we were able to construct and measure a combination of off the shelf technology to yield a modified spectrum IRL assembly that met the EISA 2007definition of modified spectrum and qualified for clear TSL 4. The table below details the various combinations of clear base case IRLs and their modified spectrum counterparts. The graph that follows depicts the clear base case lamps with corresponding modified spectrum assemblies that met the EISA 2007 definition of modified spectrum.

Table 4. Off-the-Shelf Clear and Modified Spectrum Assemblies

	Burner Source	Reflector Source	Lens Type	Lens Source	MS TSL level	Clear TSL level	Lumens	Watts	lm/W	% Lumen Reduction from MS Lens	MacAdam Steps away from Base Case	Meets EISA 2007 Definition of Mod Spec?
Clear Base Case 2	Philips Halogena ES	Philips Halogena ES	Clear	Philips Halogena ES	N/A	4	1530	72	21.3	N/A	N/A	N/A
Mod Spec 2-A	Philips Halogena ES	Philips Halogena ES	Mod. Spec.	Sylvania Daylight	4	3	1251	72	17.4	18%	6.54	Yes
Mod Spec 2-B	Philips Halogena ES	Philips Halogena ES	Mod. Spec.	GE Reveal	5	4	1427	72	19.9	6.7%	2.78	No
Clear Base Case 3	Philips Halogena ES	GE HIR	Clear	Philips Halogena ES	N/A	5	1711	72	23.9	N/A	N/A	N/A
Mod Spec 3-A	Philips Halogena ES	GE HIR	Mod. Spec.	Sylvania Daylight	5	4	1412	72	19.7	17%	5.77	Yes
Mod Spec 3-B	Philips Halogena ES	GE HIR	Mod. Spec.	GE Reveal	5	4	1562	72	21.8	9%	2.28	No
Clear Base Case 4	GE HIR	Philips Halogena ES	Clear	Philips Halogena ES	N/A	4	1122	58	19.2	N/A	N/A	N/A
Mod Spec 4-A	GE HIR	Philips Halogena ES	Mod. Spec.	GE Reveal	5	3	1031	59	17.6	8.1%	3.5	No
Clear Base Case 5	GE HIR	GE HIR	Clear	GE HIR	N/A	5	1229	59	21.0	N/A	N/A	N/A
Mod Spec 5-A	GE HIR	GE HIR	Clear	Sylvania Daylight	5	3	1025	58	17.6	17%	6.6	Yes

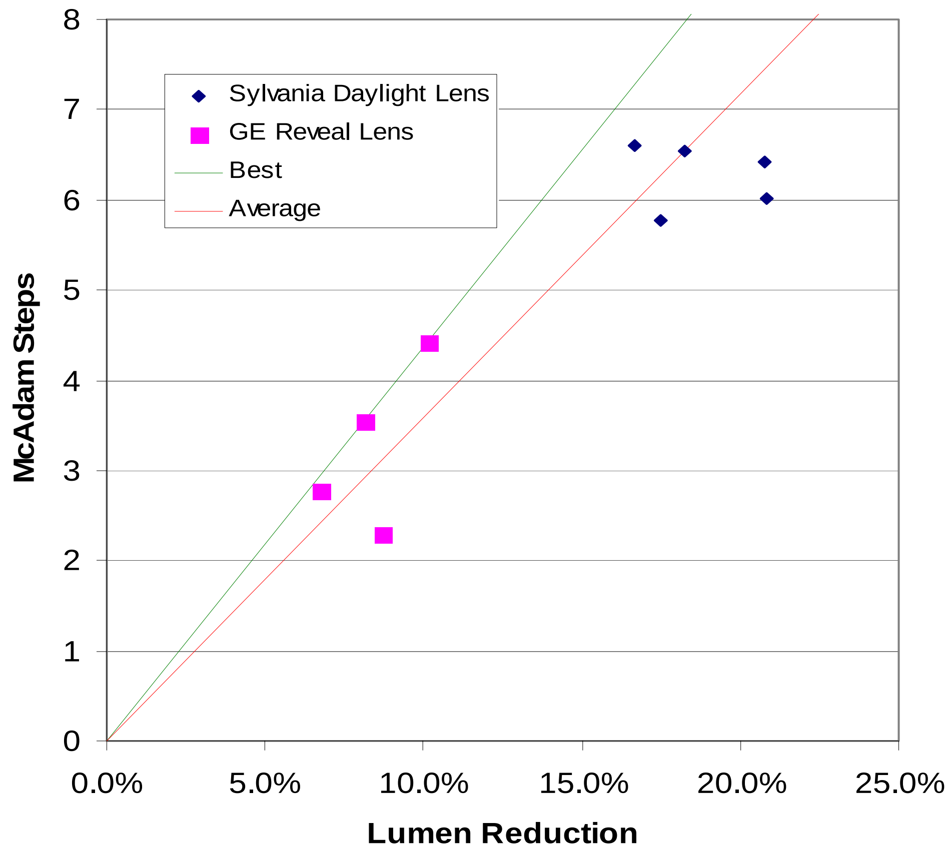
Figure 11. Clear Base Case IRLs and Modified Spectrum Counterparts Compared to Clear TSLs



As mentioned earlier, some of our modified spectrum lamp assemblies exhibited a relatively low light loss percentage but did not shift the color enough to meet the EISA 2007 modified spectrum definition. (These lamps exhibited less-than 4 MacAdam step shifts.) Other lamps shifted the color far more (6 -7 MacAdam steps) than is required by the EISA 2007 definition of modified spectrum, but also had quite high light output reductions—up to 18%. To determine the anticipated light loss if manufacturers were to target a 4 – 4.5 MacAdam step shift, we interpolated the lumen reduction and MacAdam step data from all nine of our modified spectrum lamp assemblies. The conclusion is that this color difference can be achieved with a loss of output in the range of 9% to 11%, or less.

The best measured result was a 3.55-step change with 8.1% light loss. This would imply that, with a slightly higher tint (neodymium or other) concentration, a difference of 4 MacAdam steps would require 9.1% light loss. Considering all nine test pairs similarly, the average is an 11.1% light loss. Five of the nine test pairs had a light loss less than this amount. Thus, we concluded that the 4-McAdam step color difference can certainly be achieved with a light loss of 9.1%. By adjusting other design parameters as well, it is undoubtedly possible to do better still. See graph below.

Figure 12, MacAdam Step and Light Lumen Reduction Interpolation



Conclusions & Recommendations

We can draw three key conclusions from these findings:

First, the technology exists to achieve radically higher incandescent reflector lamp efficiencies than are routinely seen in the commercially available products sold today. As Figure 3 demonstrates, the combination of a highly efficient double-ended halogen capsule with an advanced IR coating and a silverized reflector yields **efficiency levels 59% higher than DOE's clear TSL 5 level**. Even when accounting for the optical losses associated with various modified spectrum lenses, such a product can comfortably meet clear TSL 5, without needing a special accommodation (lower efficiency requirements) for its modified spectrum status. Such a combination can also comfortably meet the EISA 2007 definition of a modified spectrum lamp, given the resulting shift in chromaticity coordinates and color temperature.

Second, with the conventional IRLs sold today, differences in burner technology and reflector technology can each account for shifts in overall product efficiency of about 10%. This is evident in comparisons of the various base case lamps in Table 4, where overall combined lamp efficiency goes up or down by about 10% as individual changes are made to burners or reflectors. Similarly, changes of about 20% are seen when both the burner and the reflector are swapped with more efficient components. GE met clear

TSL 5 with a moderately efficient burner and an excellent reflector, while Philips nearly met clear TSL 5 with a somewhat more efficient burner and a moderately efficient reflector. Moreover, the Philips burner was able to meet clear TSL 5 when paired with the GE reflector. Additionally, infrared reflective coating technology appears to have even more room to improve the efficiency of the overall product. The Deposition Sciences capsule we tested appears capable of exceeding clear TSL 5 no matter which commercially available reflector it is paired with. The three clear lamps we tested that met clear TSL 5 exceeded it by an average of 36%.

Third, the process of modifying a lamp's spectrum to achieve a particular aesthetic effect is a mix of subjective and objective design changes. If manufacturers start with an efficient burner/reflector combination and modify the spectrum greatly, the light output losses are sufficient to prevent the resulting products from complying with DOE's clear TSL 5. If they modify the spectrum slightly less, they could likely achieve higher efficiencies – equivalent to DOE's clear TSL 4 (and possibly the clear TSL 5 level). Conversely, if they begin with a more highly efficient burner/reflector combination, they can afford to modify the spectrum to any reasonable degree and still comply on an efficiency basis at the clear TSL 5 level. Since manufacturers will be increasingly migrating to highly efficient burners in future general purpose and IRL lamps, the final decision about the magnitude of a modified spectrum adjustment should be weighted toward testing with those types of light sources as much as possible.

Given what we know now, we recommend that the DOE adopt clear TSL 5 for standard spectrum IRLs. Our testing has shown that at least three different burners from three different manufacturers can meet clear TSL 5 in combination with many different reflectors.

Losses of 10 to 21% have been observed in the lab in products that meet the EISA 2007definition of modified spectrum, depending on the efficiency and color qualities of the base case burner and reflector and the relative opacity of the modified spectrum lens employed. By interpolating data from all of our modified spectrum testing, including lamps that both met and did not meet the EISA 2007 definition of modified spectrum, we determined that with the given technology, an average light loss of 9 - 11% is sufficient to modify a lamp's spectrum by the 4 MacAdam step minimum requirement. Therefore, manufacturers who wish to modify the spectrum to achieve a particular visual effect could employ more efficient burner and/or reflector technology to compensate. The 10% light output increases that result from particular burner and reflector choices are very similar to the 10% light output decreases that result as manufacturers move from one type of modified spectrum lens to another or from a clear lens to the most efficient of the modified spectrum lenses. Our recommendation is that no light loss allowance be made for modified spectrum lamps. If the DOE does allow modified spectrum lamps to be dimmer, we recommend that the maximum allowance be 10%.

Finally, it is also evident that manufacturers have other means of modifying a lamp's spectrum beyond the use of absorptive elements within the glass cover. The same types of optical films that can be tailored to reflect portions of the infrared spectrum back onto a filament could, in principle, be tailored to reflect portions of the visible spectrum back onto the filament as well. This would modify the spectrum in a more efficient way, "reusing" the light.