APPENDIX 5D. ADVANCED IR COATINGS

TABLE OF CONTENTS

5D.1 INTRODUCTION 5D-1
5D.2 BACKGROUND 5D-1
5D.2.1 HIR Technology 5D-1
5D.2.2 Silverized reflector coating 5D-2
5D.2.3 Alternative method 5D-2
5D.3 METHOD 5D-2
5D.3.1 Capsules 5D-2
5D.3.2 Modifying voltage 5D-3
5D.3.3 Reflector 5D-3
5D.4 RESULTS 5D-4
5D.4.1 ADLT Burners 5D-4
5D.4.2 Reflector Losses 5D-4
5D.4.2.1 Commercially Available Lamps 5D-4
5D.4.2.2 ADLT Burners 5D-5
5D.5 LONG LIFE 5D-6
5D.6 PRICE 5D-6
5D.7 CONCLUSION 5D-7

LIST OF TABLES

Table 5D.1 Test Results for Burners with Advanced IR Coating 5D-4
Table 5D.2 Test Results for Burners with Advanced IR Coating Operating at a Reduced Operating Temperature 5D-4
Table 5D.3 Test Results for Commercially Available HIR Lamps 5D-4
Table 5D.4 Calculated Efficacies for ADLT Burner-Reflector Assemblies 5D-5
Table 5D.5 Calculated Efficacy for a Long Life (6,000 hours) IRL using an ADLT Advanced IR burner 5D-6

APPENDIX 5D. ADVANCED IR COATINGS

5D.1 INTRODUCTION

Trial standard level (TSL) 5 for incandescent reflector lamps (IRL) represents a halogen infrared reflector (HIR) lamp with the most efficient infrared (IR) glass coatings, reflector coatings, or filament designs. Commercially available products currently meet TSL 5 by using a silverized reflector coating. One lamp manufacturer currently holds a patent on this technology which will not expire until after energy conservation standards take effect. In this chapter the Department of Energy (DOE) presents the results of testing performed on lamps that utilize a different technology, that is potentially available to all manufacturers, and may possibly be utilized to manufacture a lamp that would comply with TSL 5 without the use of the proprietary silver technology. In this appendix, DOE investigates not only the resulting lamp efficacy when employing the advanced IR coatings, but also investigates manufacturing costs associated with this technology. Finally, DOE also explores the potential to use this technology to manufacture high-efficacy, long-life IRL.

5D.2 BACKGROUND

5D.2.1 HIR Technology

In chapter 3 of the technical support document (TSD), DOE discusses IR glass coatings as a possible design option. When a lamp contains an IR coating, it reflects more IR radiation onto the filament, so if run at the same voltage, the lamp operates at a higher temperature. This increase in operating temperature increases light output, which in turn increases efficacy. DOE concluded that this technology met the required screening criteria outlined in chapter 4 of the TSD and considered it as a design option.

HIR lamps that are commercially available today use IR coatings with alternating layers of two materials, SiO_2 and a second material of either Ta_2O_5 or Nb_2O_5. Typical layer counts range from 45 to 75. In contrast, the most efficient HIR lamps have a coating made of three materials, SiO_2, Ta_2O_5 and TiO_2, the latter in the high - index rutile phase. This three material coating, described as a Hybrid™ by Advanced Lighting Technologies Inc. (ADLT) (hereafter referred to as advanced IR coating), has an effective IR reflectance significantly higher than that of the two-material coatings used in the commercially available examples (described in section 5D.3.1 below), resulting in enhanced lumen per watt (lm/W) values.

This advanced IR coating is **not** a developmental product. Developed at ADLT, it has been in production on 12 Volt, single-ended burners in Europe for more than two years. However, the efficacy level achieved with this coating on the single-ended configuration is lower than that realized with the double-ended burners used in the testing described below.

Neither the burner nor the coating provided to DOE requires additional development. Both are separately in production at present, not patented, and available to all lamp manufacturers. The additional layers lead to a slight increase in manufacturing time compared to the coatings currently in use in the market place.

5D.2.2 Silverized reflector coating

Though aluminum is most prevalent as a reflector coating in incandescent reflector lamps, silver coatings can also be applied. Silver coatings are generally preferred over aluminum due to their lower light loss (silver reflects about eight percent more light based on commercially available lamps). One manufacturer currently holds a patent on the silverized reflector coating technology that will not expire until December 2019[1]. Therefore DOE considered the silverized reflector coating to be a proprietary technology (see section VI.B.1 of the final rule *Federal Register* notice for a description of how DOE treats proprietary technologies). However, DOE is also aware of technology options that utilize silver to enhance reflector efficiencies but may not fall under proprietary restrictions[2] (see section VI.B.2.b of the final rule *Federal Register* notice for a description of these other technologies). However, DOE believes that significant uncertainty remains as to the successful implementation of these technologies in commercial products at the scale needed to service the IRL market. Therefore, DOE maintained that a silverized reflector required proprietary technology and thus investigated an alternative method to achieve TSL5.

5D.2.3 Alternative method

DOE investigated the possibility that TSL 5 could be achieved without using a silverized reflector coating. DOE reviewed design options that met all required screening criteria (see chapter 4 for details) and discovered the existence of a more efficient IR coating than that currently in use in the lighting industry.

To prove the effectiveness of this coating, ADLT obtained commercially available capsules, applied the advanced IR coating, and sent the capsules to the Lighting Research Center (LRC) in Rochester, NY for independent testing. The following sections describe the method the LRC used for testing and the results of that testing.

5D.3 METHOD

5D.3.1 Capsules

ADLT provided the LRC with IR coated halogen burners for evaluation. ADLT informed DOE that when used with the two-material coating for which they were originally designed, these burners operate at 60 W, delivering 24 lm/W. The design life and temperature are 3000 hrs

and 2880 K. They are double-ended, elliptical quartz burners, with lengths of 4.5 cm, excluding the electrodes, and minor elliptical axes of 1.0 cm.

This shape and size readily accommodates use in most IRL, as evidenced by products now on the market. ADLT claims that such products exist in R20, BR30, BR40 and PAR38 formats. In addition, outside the IRL configuration, ADLT claims that a commercially-available A-line general service incandescent lamp incorporates a burner of the same shape and size. These commercially available examples operate at 120V at various powers. The LRC measured the lumens and watts of these capsules according to DOE's test procedure for testing incandescent reflector lamps (title 10 Code of Federal Regulations (CFR) part 430, subpart B, appendix R).

5D.3.2 Modifying voltage

As mentioned in section 5D.2.1, IR coatings increase the operating temperature of an HIR lamp, which in turn decreases the lifetime. According to ADLT, commercially available halogen burners with standard IR coatings have rated lifetimes of approximately 3,000 hours when operated at 120V. Because the advanced IR coating reflects more IR radiation than the standard IR coating, the lamp's operating temperature increases, resulting in a decrease of lamp lifetime. ADLT performed tests and determined that the burners with the advanced IR coatings supplied by ADLT have lifetimes of approximately 1,200 hours. In order to determine the efficacy of a 3,000 hour lamp with an advanced IR coating, DOE lowered the operating voltage of the ADLT burners such that the measured correlated color temperature (CCT) (representative of operating temperature) was the same as that of the commercially available lamp with the standard IR coating. DOE assumed this modification reasonably approximated a 3,000 hour lamp.

5D.3.3 Reflector

A burner and reflector combined emit less light than the burner alone due to light losses attributable to the reflector. Because the burners provided by ADLT are not sold commercially as a reflector lamp assemblies, DOE calculated the potential efficacy of an IRL utilizing an advanced IR coated burner. To do this, DOE first calculated the lumen reduction due to reflectors in commercially available lamps. DOE then applied these same percentage lumen reductions to the burners provided by ADLT.

The LRC bought and analyzed five existing lamps from two different manufacturers to evaluate the lumen losses due to reflectors. It tested each burner-reflector assembly and burner (separate from the reflector) three times and averaged the measured lumens across the three tests. Using these average lumens from the burner and the average lumens from the burner-reflector assembly, DOE then calculated the percent lumen loss due to each lamp reflector. DOE applied this percentage to calculate the lumen loss due to a reflector for the burners supplied by ADLT.

5D.4 RESULTS

5D.4.1 ADLT Burners

Table 5D.1 shows the average lumens, power, and efficacy of the ADLT burners at 120V, whereas Table 5D.2 below shows the same metrics with the burners operating at reduced temperature. As seen in the tables below, reducing the operating temperature to obtain a lifetime of 3,000 hours instead of 1,200 hours results in a decrease in efficacy of about 5.6 lm/W.

Table 5D.1 Test Results for Burners with Advanced IR Coating

		Reflector & Burner	Burner
Average Light Output	lumens	-	2116.9
Average Power	watts	-	57.0
Average Efficacy	lm/W	-	37.1
Average Voltage	V		120

Table 5D.2 Test Results for Burners with Advanced IR Coating Operating at a Reduced Operating Temperature

		Reflector & Burner	Burner
Average Light Output	lumens	-	1513.8
Average Power	watts	-	48.1
Average Efficacy	lm/W	-	31.5
Average Voltage	V	-	107

5D.4.2 Reflector Losses

5D.4.2.1 Commercially Available Lamps

The LRC tested each commercially available burner and burner-aluminum reflector assembly three times for repeatability and calculated an average value. The average lumens, watts, and efficacies for the five commercially available lamps are shown in Table 5D.3.

Table 5D.3 Test Results for Commercially Available HIR Lamps

			Reflector & Burner	Burner
Manufacturer A	Average Light Output	lumens	993.3	1358.3
	Average Power	watts	61.3	61.7
	Average Efficacy	lm/W	16.2	22.0
Manufacturer	Average Light Output	lumens	978.0	1151.7

A	Average Power	watts	56.6	56.9
	Average Efficacy	lm/W	17.3	20.2
Manufacturer A	Average Light Output	lumens	983.7	1141.0
	Average Power	watts	53.6	53.7
	Average Efficacy	lm/W	18.4	21.2
Manufacturer B	Average Light Output	lumens	780.3	975.9
	Average Power	watts	51.7	51.8
	Average Efficacy	lm/W	15.1	18.9
Manufacturer B	Average Light Output	lumens	1057.0	1349.0
	Average Power	watts	62.1	62.3
	Average Efficacy	lm/W	17.0	21.7

As shown in the table above, Manufacturer A's best reflector maintains 86.2% of the light from the capsule alone, whereas the worst reflector maintains 73.1% of the light. Manufacturer B's best reflector maintains 79.9% of the light from the capsule alone, whereas the worst reflector maintains 78.4% of the light. Using these percentages, it is possible to calculate a best and worst case scenario. The best case scenario would use the reflector that maintains 86.2% of the light, where as the worst case scenario would use the reflector that maintains 73.1% of the light.

5D.4.2.2 ADLT Burners

Using the percentages described in the previous section, DOE calculated the most efficient and least efficient burner-reflector combination that uses the ADLT burners. Table 5D.4 shows the results.

Table 5D.4 Calculated Efficacies for ADLT Burner-Reflector Assemblies

			Reflector & Burner	**Burner**
Best Case Scenario, 86.2% reflector	Average Light Output	lumens	1305	1513.8
	Average Power	watts	48.1	48.1
	Average Efficacy	lm/W	27.1	31.5
Worst Case Scenario, 73.1% reflector	Average Light Output	lumens	1107	1513.8
	Average Power	watts	48.1	48.1
	Average Efficacy	lm/W	23.0	31.5

As outlined in section VII.A.2 of the final rule, energy conservation standards for IRL are dependent upon the wattage of the lamp. The relevant equation that defines the minimum efficacy standard associated with TSL 5 is $6.4P^{0.27}$, where P is the rated wattage. If 48W were the rated wattage of the lamp in the table above, the corresponding efficacy level at TSL 5 would be 18.2 lm/W. With an efficacy of at least 23.0 lm/W, the ADLT burner-reflector assembly would meet TSL 5. As TSL 5 represents the highest efficacy level, the ADLT burner-reflector assembly would also meet all other TSLs.

5D.5 LONG LIFE

As discussed in section 5D.2.1, HIR technology results in lamps operating at higher temperatures. This, in turn, decreases lamp lifetime because the tungsten filament evaporates more quickly. Therefore, DOE performed an analysis to investigate how utilizing an advanced IR coating to meet TSL 5 would affect long-life HIR lamps.

Using the 9th edition of the IESNA Lighting Handbook[3], DOE developed a relationship between lifetime, lumens, and wattage for two different lamps. Using the known power, lumens, and lifetime for the 3,000 hour improved HIR lamp, DOE was able to calculate the lumens of the HIR lamp if it had the same power but a lifetime of 6,000 hours. Table 5D.5 shows the calculated lumens and efficacy for a 6,000 hour HIR lamp that employs an advanced IR coating.

Table 5D.5 Calculated Efficacy for a Long Life (6,000 hours) IRL using an ADLT Advanced IR burner

			Reflector & Burner
Best Case Scenario, 86.2% reflector	Average Light Output	lumens	1188
	Average Power	watts	48.1
	Average Efficacy	lm/W	24.7
Worst Case Scenario, 73.1% reflector	Average Light Output	lumens	1007
	Average Power	watts	48.1
	Average Efficacy	lm/W	21.0

As described in section 5D.4.2.2, the minimum efficacy requirement at each TSL varies based on the rated wattage of the lamp. If the rated wattage of the above lamp were 48W, the corresponding minimum efficacy requirement at TSL 5 would be 18.2 lm/W. As shown in Table 5D.5, both the best case and worst case scenarios meet TSL 5. However, DOE recognizes that these efficacies do not represent lamp efficacies under mass production. Therefore, DOE cannot conclusively determine that long-life lamps wouild be available at TSL5.

5D.6 PRICE

To consider this advanced IR technology as an alternate technology pathway to achieve TSL5, DOE also analyzed potential manufacturing cost and price impacts to this technology. ADLT provided DOE with estimates of the cost of applying the advanced IR coating described in section 5D.2.1 to an existing capsule. It estimated the cost to the lamp manufacturer of adding the advanced IR coating to be $0.68 per burner if one million capsules were coated per year[4]. Lamp manufacturers have the option of paying ADLT to apply the advanced IR coating or acquiring a machine and coating their own lamps. ADLT expects the price to decrease to $0.20 per burner if 500 million or more capsules were coated per year.

To best determine the price of a lamp with an advanced IR coating, DOE added the incremental cost of the advanced IR coating to the price of a lamp at TSL 4 (see TSD chapter 7). TSL 4 is represented by a HIR lamp with a standard IR coating and a 4,000 hour lifetime. ADLT estimated the cost of a standard IR coating, described in section 5D.2.1, to be $0.50 per burner if one million capsules were coated per year, decreasing to $0.15 per burner if 500 million or more burners were coated per year. Therefore, based on these numbers, the incremental cost to manufacturers of the advanced coating would be approximately $0.18 per burner in small quantities or $0.05 per burner in large quantities.

In consideration of the current state of the technology and its production volume, a lamp currently manufactured with this advanced IR coating technology would be subject to lower volume cost estimates. In the manufacturer impact analysis (MIA), DOE used a multiplier of 2.3 to calculate the end-user price given the cost to the lamp manufacturer. Using this multiplier, the manufacturer cost differential between a standard IR coated lamp and an advanced IR coated lamp results in an incremental cost of $0.41 to the end user. Adding this incremental cost to the price of a lamp at TSL 4, DOE calculates the medium price of a PAR38 lamp with an advanced IR coating at TSL 5 to be $7.91 and calculates the medium price of a PAR30 lamp to be $7.34.

5D.7 CONCLUSION

As shown in section 5D.4.2.2, testing indicates that it is possible to achieve TSL 5 without using a silverized reflector. An advanced IR coating, which, to DOE's knowledge, would be available to all lamp manufacturers, can likely be used to meet TSL 5. In addition, as shown in section 5D.5, TSL 5 does not appear to eliminate long-life lamps from the market. Using a relationship derived from the IESNA Lighting Handbook, DOE tentatively concluded that a 6,000 lamp with an advanced IR coating could still achieve TSL 5.

In section 5D.6, DOE calculated the cost of a lamp with an advanced IR coating by adding the incremental cost of the coating to the price of a lamp at TSL 4. The analysis found these prices to be comparable with IRL that meet TSL 5 and utilize the proprietary silverized reflector technology.

Although these results show that IRL with an advanced IR coating can meet and exceed TSL5, DOE does not believe that this data is representative of the efficacy these lamps will achieve when manufactured on a large scale. Large scale production will likely result in decreased efficacy, though the magnitude of this reduction is uncertain (see section VI.B.2a of the final rule *Federal Register* notice for more details). Therefore, DOE cannot conclusively determine the performance of lamps utilizing the advanced IR coatings when manufactured on a large scale.

REFERENCES

[1] Zhao, Tianji, et al. "Protected Coating for Energy Efficient Lamp." U.S. Patent 6,773,141. August 10, 2004.

[2] Deposition Sciences Incorporated. *In Development – New, Improved & Enhanced Silver Coating*. (Last Accessed July 7, 2009) <http://www.depsci.com/Documents/SubHeading/DSIannouncesEcoWhiteFINAL.pdf>

[3] Rae, Mark S., ed. The IESNA Lighting Handbook, Reference & Application, 9th edition, New York, NY, IESNA 2000.

[4] Boling, Norm. <bolingn@depsci.com> "FW: pricing" 8 December 2008. Personal email. (9 December 2008).