Next Generation Lighting
INDUSTRY ALLIANCE

ALLIANCE ADMINISTRATION

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Back-up (supporting) information for the numbers cited in the NGL Industry Alliance Handout Sheet at the Sept. 11 2003, Technology Demonstration in the Dirksen Building

Questions:

1. How big is the global lighting industry (that is, sales of lamps, ballasts, luminaires and lighting controls)? The domestic lighting industry?
2. What fraction of our domestic electrical energy use is for lighting?
3. How much electrical energy does the U.S. use for lighting? How much does this cost?
4. How many incandescent lamps are used in the U.S.? How much energy is used to operate these lamps? What is the market cost of electricity to operate these lamps?
5. When solid state lighting reaches 150 lumens per watt (about 10 times the efficiency of incandescent lamps, and about twice that of fluorescent lamps), how much energy can be saved in the U.S. annually?
6. What are the dollar savings in electricity that can be saved when solid state lighting reaches 150 lumens per watt?
7. What other environmental benefits (associated with the savings in electrical energy) can be realized when solid state lighting reaches 150 lumens per watt?

	Assumptions / Explanations / References
1	On average, the lumen maintenance is the same for white LEDs/OLEDs, incandescent / halogen, and fluorescent lamps. For example, over a fixed period of time, the average delivered lumens of these sources is the same, if they start out with the same luminous flux and if shorter lived lamps are replaced (with lamps of the same initial luminous flux) when they fail. In other words, lumen maintenance is not considered as a distinguishing feature of one lamp type vs another.
2	When all factors are considered (LED directionality, necessity of color mixing with some white LED lighting schemes, the use of various white light generating schemes for OLEDs, etc.), the luminaire loss (optics loss) for LEDs/ OLEDs, averaged over all general illumination applications, is assumed to be the same as that for incandescent and fluorescent lighting systems.
3	The production of 1 watt of fluorescent lamp power generates 0.125 watts loss in the ballast.
4	The production of 1 watt of LED or OLED lamp power generates 0.125 watts loss

	in the driver.
5	The number of lamp sockets for each lamp type, their distribution across applications, and energy consumption for these sockets is unchanged from 2001 (as reported in the DOE-Navigant National Lighting Inventory [NLI]).
6	Average electricity prices for incandescent and fluorescent lamps were calculated based on the sectors and annual energy consumption reported in the NLI. With incandescent lamps operating primarily in the residential sector and fluorescent lamps operating primarily in the commercial sector, the national usage-weighted electricity price is different. The national average electricity cost for incandescent lamps is \$0.079/kWh and for fluorescent lamps is \$0.069/kWh. [Sources: The National Lighting Inventory and The Energy Information Administration's Electric Power Monthly, May 2003 Edition, Table 5.6B] Over all lighting applications and sectors, the national average cost of electricity is \$0.073.
7	The average efficacies of incandescent and fluorescent sources are unchanged from 2001 (as reported in the DOE-Navigant National Lighting Inventory [NLI]).
8	Any net energy savings from the reduced demand for space cooling (due to more efficient lighting) is not considered (included) in these calculations.
9	A typical large power plant is assumed to have a 1000 MW (1 GW) electrical output [secondary energy, or site energy]. Over a year, power plants are taken off-line for maintenance, thus they are operational (or "available") for part of the year. Considering all fuel types, and all power plant sizes, the availability of power plants in the U.S. was 87.0% in 2001. Thus for these calculations, a 1 GW power plant's annual output is taken to be: 1 GW x 8760 hr/yr x 0.87 = 7621 GWh or 7.62 x 10^{12} watt-hours. [Availability source: North American Electric Reliability Council, Generating Availability Data System, March 6, 2003]
10	In the conversion of primary energy (coal, natural gas, nuclear fuel) to electrical energy (watt-hours), about two-thirds of the primary energy is consumed. Each year, the national average conversion ratio for primary energy to electrical energy varies slightly with changes in the fuel generation mix. In 2001, the national average conversion ratio was 3.156 (derived from footnote 8, p. 60 of the NLI), meaning for 1 unit of electrical energy on site, 3.156 units of primary energy were needed at the power plant. Primary energy is usually expressed in Quads (for quadrillion BTUs) and electrical energy (secondary energy, or site energy) is usually expressed in watt-hours. Thus, in 2001, it took 3.156 Quads of primary energy to generate 1 Quad of site electrical energy, or 293 x 10^{12} watt-hours of site energy.
11	Incandescent lamps occupy about 98% of the total "incandescent + halogen" sockets. (See p. 35, Table 5-4 of the NLI.) It is assumed that incandescent lamps also consume 98% of the total "incandescent + halogen" electrical energy and deliver 98% of the total "incandescent + halogen" lm-hrs.
12	Note that this calculation does not assume that LEDs replace any halogen lamps. This was done to keep the story simpler. If we were to assume that LEDs will also replace half of all halogen lamps as well, the answers are not much different (1-2%) because, relatively speaking, there are so few halogen lamps.
13	Note that nowhere do we give a target date for reaching the 150 lm/W figure. (The dates would surely be different for LEDs and OLEDs in any case.)

	Common “facts” and projections (the “answers”)
1	The size of the global lighting industry (sales of lamps, ballasts, luminaires, and lighting controls) is $40B. The size of the U.S. lighting industry is $12B.
2	Electrical lighting today (2001) consumes 22% of the total U.S. use of electrical energy.
3	In the U.S. in 2001, lighting consumed enough electrical energy to absorb the output of 100 large power plants. More than 3X this much energy was used to generate the electricity. The market cost of this electricity was $55 B.
4	In the U.S., there are over 4.2 billion incandescent lamps in use. (This is the number of incandescent sockets in use, not the number of incandescent lamps sold annually.) They consume enough energy to absorb the output of 41 large power plants. More than 3X this much energy was used to generate the electricity. The market cost of this electricity was about $25 B.
5	When LEDs / OLEDs reach 150 LPW, we will save annually the output of about 30 large power plants. This assumes: (1) with this efficacy SSL will replace half of all incandescent and fluorescent lamps, which we believe it will; and (2) the total energy used for lighting, and the pattern of lighting applications, are unchanged from today (2001). This energy savings represents 6-7% of the country’s total electrical energy usage.
6	When LEDs / OLEDs reach 150 LPW, we will save about $17 B annually in electricity costs.
7	Associated with the energy savings equivalent to 30 large power plants (from #5 above) are these additional environmental savings associated with the generation of electrical energy: (1) over 40 million tons of carbon release, or 150 million tons of CO_2; (2) 1/3 of a million tons of NO_x; and (3) 2/3 of a million tons of SO_2.

	Back-up for common "facts" and projections
1	NEMA estimates.
2	Taken directly from p. 60 of the NLI document. Also can be deduced from the numbers on pgs. 59-60, Figures 8-1 and 8-2: 37 Quads of primary energy consumed for electricity consumption, 8.2 Quads of this for electricity for lighting.
3A	from p. 63 of the NLI: total lighting energy consumption in 2001 [SECONDARY ENERGY] = 764.7 x 10^{12} Wh A typical large power plant generates 1 GW. Over the course of a year (8760 hours) this generates 8760 x 1 x 10^{9} Wh of energy, or 8.76 x 10^{12} Wh. The power plant is available only 87.0% of the time, for a net annual energy delivered of 7.62x10^{12} Wh. (See assumption 9.) 764.7 x 10^{12} Wh / 7.62 x 10^{12} Wh/power plant = 100.35 power plants From the DOE, I obtain this conversion factor: on average in the U.S, it takes 3.156 units of primary energy to produce 1 unit of site (secondary) electrical energy
3B	764.7 x 10^{12} Wh x (1 kWh/10^{3} Wh) x ($0.073 / kWh) = $55.8 B
4A	The 4.2 billion comes from p. 35, Table 5-4 of the NLI.
4B	Page 63 gives the energy consumption of "incandescent + halogen" lamps as 321.2 x 10^{12} Wh per year. Since incandescent lamps are about 98% of the total "incandescent + halogen" lamps (p. 35 of NLI) I estimate that incandescent lamps use 98% of the 321.2 x 10^{12} Wh, or x 3.15 x 10^{14} Wh. (Halogen lamps are somewhat more efficient than incandescent lamps, and they have better lumen maintenance. Still, while there is some structural inaccuracy introduced, I think it is lost in the noise.) 3.15 x 10^{14} Wh / (7.62 x 10^{12} Wh/power plant) = 41.3 power plants
4C	3.15 x 10^{14} Wh x (1 kWh/10^{3} Wh) x ($0.079 / kWh) = $24.88 B
5	From p. 39 of NLI, incandescent/halogen lamps generated 4.614 x 10^{15} lumen-hours in 2001. From p. 63 of NLI, incandescent/halogen lamps consumed 321.2 x 10^{12} Wh in 2001. The average efficacy = 4.614 x 10^{15} lumens / 321.2 x 10^{12} watts = 14.4 lm/W. The efficacy of halogen lamps is somewhat higher than incandescent lamps, but the impact on this average number is small (especially since halogen lamps often are manufactured to have longer lives, which lowers their effective efficacy advantage). Take 14.4 as the average efficacy of incandescent lamps. Estimate the total lumens produced by incandescent lamps as 98% of the lumens produced by the total "incandescent + halogen" lamps, which is 4.614 x 10^{15} lm-hrs (from Table 5-8, p. 39 of the NLI). 98% of this is 4.52 x 10^{15} lm-hrs. In our working model, we want to identify the savings associated with replacing half of these incandescent lamps. Half of the lamps generate half of the lumen-hours, or 2.26 x 10^{15} lm-hrs.

We want to replace these 2.26 x 1015 lm-hrs from incandescent lamps with light from LEDs which operate at an efficacy of 150 lm/W before driver losses, or 150 lm/W /1.125 = 133.3 lm/W including the driver loss (see assumption 4).

The energy saved from replacing half of the light from incandescent lamps with light from LEDs will be:
2.26 x 10^{15} lm-hrs x ((1/14.4 lm/W) – (1/133.3 lm/W) = 1.40 x 10^{14} Wh
Expressed in power plants: 1.40 x 10^{14} Wh / 7.62 x 10^{12} Wh/power plant = 18.37 power plants

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Now this calculation has to be repeated for the half of fluorescent lamps to be replaced:

From p. 39 of NLI, fluorescent lamps generated 23.732 x 10^{15} lm-hrs in 2001.
From p. 63 of NLI, fluorescent lamps consumed 313.4 x 10^{12} Wh in 2001.
The average efficacy = 23.732 x 10^{15} lumens / 313.4 x 10^{12} watts = 75.7 lm/W
With ballast loss: (75.7 lm/W) / 1.125 = 67.3 lm/W (see assumption 4).

The total lm-hrs produced by fluorescent lamps in a year is 23.732 x 10^{15} (from Table 5-8, p. 39, of the NLI). Half of the fluorescent lamps generate half this amount, or 11.866 x 10^{15} lm-hrs.

We want to replace these 11.866 x 10^{15} lm-hrs with light from LEDs, which operate (including driver loss) at 133.3 lm/W (see above).

The energy saved from replacing half of the light from fluorescent lamps with light from the LEDs will be:
11.866 x 10^{15} lm-hrs x ((1/67.3 lm/W) – (1/133.3 lm/W) = 8.73 x 10^{13} Wh
Expressed in power plants: 8.73 x 10^{13} Wh / 7.62 x 10^{12} Wh/power plant = 11.46 power plants

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Adding the incandescent and fluorescent contributions to the energy savings:
Total Wh saved = 1.40 x 10^{14} Wh + 8.73 x 10^{13} Wh = 2.27 x 10^{14} Wh
Total power plants saved = 18.37 + 11.46 = 29.83

According to the NLI, the total (site) electrical energy used in the U.S. in 2001 was 37 Quads / 3.156 (the 37 Quads comes from p. 59 and the 3.156 factor (primary to secondary conversion) from the footnote on p. 60), or 11.7 Quads.
11.7 Quads x 2.93 x 10^{14} Wh / Quad = 3.43 x 10^{15} Wh. The total energy saved by the conversion of half of all incandescent and fluorescent lamps to LEDs was calculated to be 2.27 x 10^{14} Wh. This is (2.27 x 10^{14} Wh)/ (3.43 x 10^{15} Wh) = .066, or 6.6% of the total electrical energy used in the country in 2001.

	Or viewed more simplistically, it was calculated in (3A) above that in 2001 lighting consumed electrical energy about equal to the output of 100 large power plants. It was calculated above that the LED conversion described would save energy roughly equal to the output of 30 large power plants. Since lighting consumed about 22% of all the electrical energy in the country in 2001, the energy savings due to the conversion to LEDs represents about 22% x 30/100 = 6.6% of the country’s total electrical energy usage in 2001.
6	The cost savings have to be calculated separately for the incandescent lamps replaced and the fluorescent lamps replaced, since the 2 different lamp types have different costs of energy due to their different application arenas (see assumption 6). Incandescent savings: 1.40 x 10^{14} Wh x (1 kWh/10^{3} Wh) x \$0.079 /kWh = \$11.06 B Fluorescent savings: 8.73 x 10^{13} Wh x (1 kWh/10^{3} Wh) x \$0.069 /kWh = \$6.02 B Total savings: \$11.02 = \$6.02 = \$17.08 B annually, based on 2001 energy use level and distribution of lamps and lighting applications
7	Total Wh savings from [7] are 2.27 x 10^{14} Wh. Note that this is site, or secondary energy. Convert this to Quads of primary energy: 2.27 x 10^{14} Wh x (1 Quad / 2.93 x 10^{14} Wh) x (3.156 units primary/secondary) = 2.445 Quads. Note that 1 Quad is 1 x 10^{15} BTUs, by definition.. Carbon / CO_2 calculation from p. 46 of DOE Solicitation DE-PS26-03NT41635-01, the fuel-specific carbon emission factor for electricity is 15.67 Kg carbon /MM BTU of primary energy (2.445 x 10^{15} BTU) x (15.67 kg carbon/10^{6} BTU) x 1 metric ton / 10^{3} kg = 38.3 x 10^{6} metric tons carbon, or **38.3 million metric tons of carbon** to convert tons of carbon to tons of CO_2, multiply by 44/12 = 3.67: 38.3 x 3.67 = 140.56; so, **140.56 million metric tons of CO_2** NO_x, SO_2 calculations from “Emission Factors and Energy Prices for the Cleaner and Greener Environmental Program, Jan. 2003, prepared by Leonardo Academy Inc. for the Multiple Pollutant Emission Reduction Reporting System (MPERRS), with funding by the Wisconsin Dept. of Natural Resources and the U.S. Environmental Protection Agency, Table 3: for electricity generation in the U.S.,

there is 0.00297 lbs of NO_x emitted for each 1.392 lb of CO_2, and 0.00604 lb of SO_2 emitted for each 1.392 lb of CO_2.
So: for each pound of CO_2 emitted there is (.00297/1.392) pounds of NO_x, or 2.13×10^{-3} pounds of NO_x
So: for each pound of CO_2 emitted there is (.00604/1.392) pounds of SO_2, or 4.34×10^{-3} pounds of SO_2

Amount of NO_x emissions saved is:
($140.56 \times 2.13 \times 10^{-3}$) million metric tons = **0.30 million metric tons NO_x**

Amount of SO_2 emissions saved is:
($140.56 \times 4.34 \times 10^{-3}$) million metric tons = **0.61 million metric tons of SO_2**

The above results need to be converted from metric tons to "U.S. standard" tons to be user-friendly. Convert all of above from metric tons to tons:

factor to use: 1000 kg/MT x 2.2046 lbs/kg x 1 ton/2000 lbs = 1.1023 ton/MT
So:
carbon: $1.1023 \times 38.3 \times 10^6$ = **42.2×10^6 tons of carbon**
CO_2: $1.1023 \times 140.56 \times 10^6$ = **154.9×10^6 tons of CO_2**
NOx: $1.1023 \times 0.30 \times 10^6$ = **0.33×10^6 tons of NO_x**
SO_2: $1.1023 \times 0.61 \times 10^6$ = **0.67×10^6 tons of SO_2**