A Market Transformation Opportunity Assessment for LED Traffic Signals

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EXECUTIVE SUMMARY

Light emitting diode (LED) light sources for traffic signals offer significant energy savings over the incandescent lamps traditionally used in this application. LED signals also last much longer than incandescent signals and fail less frequently, offering additional savings in reduced relamping, routine and emergency maintenance, and liability costs. Energy savings alone are estimated to be 3 billion kWh per year nationwide — a cost savings of $225 million per year — with maintenance and liability benefits on the same order of magnitude.

The market for traffic signals is clearly moving in the direction of LEDs. As of April 1996, 25,000 signal heads in the United States had been retrofitted with LEDs. Just a year an a half later, by the end of 1997, an estimated 150,000 LED traffic signals had been installed. This year, manufacturers expect that installations will double. The vast majority of these retrofits, however, have been for red LED traffic signals. Green and yellow retrofit kit sales are much lower and an integrated three-color LED traffic signal is in the early development stages.

A number of obstacles stand in the way of more rapid market penetration:

- *Uncertainties about performance*. Lack of information, lack of time to research information (i.e., high information or search costs), mistrust of potentially biased data (e.g., where the key source of technical and performance information is manufacturers), and the absence of a national specification all contribute to concerns about the technology's performance.

- *Organizational practices and customs.* State and local policy development, procurement, and capital and operating budgeting processes, as well as limited capital availability in many government agencies, limit investment in LED traffic signals.

- *High product costs.* High product costs (particularly for green LED retrofit kits) that result from inherently more costly technology, limited competition among source material manufacturers, and brightness standards (thought by many to be more stringent than necessary) hinder the LED traffic signals market.

Despite these barriers, a handful of communities and states throughout the country have retrofitted at least some of their red traffic signals with LEDs (and some have experimented with two- and three-color retrofits). As a result of their experience, many of these states and local governments are choosing to move to full-scale LED retrofits. In the absence of a national specification, several of these jurisdictions have developed their own specifications. Utilities and other third parties have helped to spur the market by offering rebates and financing for LED signals and by educating decision-makers

LED traffic signals appear to be a good candidate for what could be a relatively easy market transformation effort. Accelerating market acceptance of red LED traffic signals is likely to require a relatively modest effort focused on activities such as developing and disseminating case studies, deploying targeted demonstration projects, making financing more easily available, and to a lesser extent working with national and regional organizations on specification development (for those states and localities reluctant to proceed without a national specification).

For red and green signals to be more attractive to jurisdictions, the cost of green LEDs will have to come down and/or the additional maintenance and other benefits from the two-color change-outs will have to be highlighted. Again, case studies and demonstrations can provide information on the actual benefits realized from retrofits, and financial incentives to spur the market as well as longer term financing can help address capital constraints faced by many states and localities. In addition, more critical than with red signals alone is influencing the development of a national specification by working with the Institute for Traffic Engineers (ITE) and supporting or supplementing current research on signal brightness requirements, as current levels are believed to contribute to the high cost of green and yellow signals.

Making three-color signals a market reality can be facilitated by working with manufacturers to develop fully integrated three-color LED traffic signals, and with state and local governments to demonstrate the signals' effectiveness. In addition to energy and maintenance savings (not much greater than two-color retrofits because of the low duty factor of yellow signals), some economies of scale are anticipated from system integration as are additional benefits, e.g., lighter weight, ease of use with newer traffic system controls, and reduced occupational hazard.

INTRODUCTION

As a replacement for incandescent lamps in traffic signals, light-emitting diode (LED) sources offer potential energy savings of nearly 3 billion kWh per year nationwide. These signals also last considerably longer than incandescent signals and fail less frequently, thereby providing additional savings in reduced routine and emergency maintenance costs. The significance of the energy savings and other benefits of LED traffic signals has come to the attention of the efficiency community. In fact, several utilities currently offer rebates or financing for the purchase of LED traffic signals in their service territories, and a few states and localities have developed LED traffic signal purchasing specifications.

To date, however, no comprehensive analysis of the need and potential for further intervention in this market has been conducted. In this paper we summarize our research and findings on current traffic signal market conditions, where the market is headed, and the opportunities for intervention in the marketplace. We do not, however, attempt to predict the rate of LED traffic signal technology adoption with or without specific market interventions, nor do we suggest specific, local program interventions to accelerate market acceptance. Instead, we provide an up-to-date synopsis of the LED traffic signal marketplace and suggest potential interventions to generally increase the rate of market adoption. By doing so, we provide a common basis of knowledge for market transformation practitioners to determine a proper course for future actions.

Interest in exploring the market transformation opportunities for LED traffic signals was motivated in large part by members of the Consortium for Energy Efficiency (CEE). CEE is a national nonprofit, public benefit organization that develops initiatives to expand markets for highly energy-efficient technologies. These initiatives are implemented by some of it members: electric and gas utilities, regional market transformation organizations, and research and development organizations. (Other members of CEE include public interest groups and state energy offices.) CEE members have used methods such as equipment rebates and financing, resource pooling, and bulk purchasing to spur the market for a variety of energy-efficient technologies.

In researching for this report, we relied on a few key published sources, although much of the information presented was gathered through telephone interviews with traffic signal manufacturers, utility program implementors, and local (city or county) traffic engineers and project managers.

In the remainder of this report, we provide background on LED signal technology, an estimate of the national energy savings potential from LED traffic signals, status of state and local programs where significant installations have occurred or are currently underway, traffic signal market characteristics and trends, barriers to LED traffic signal installations, and possible interventions that utilities and other parties can use to address these barriers.

LED Traffic Signals: Technology and Technical Potential for Energy Savings

How LEDs Work

Most traffic signals in place today use incandescent lamps as a light source and a colored plastic or glass lens to project the red, green, or yellow colors through to oncoming viewers. Since the early 1990s, a number of municipalities and state governments have purchased LED signal head retrofit kits to replace incandescent signals. LEDs are semiconductor devices that use solid-state electronics to create light. A LED light source (or die) consists of a layer of electron-rich material separated by a junction from a layer of electron deficient material, both sitting on a semiconductor base. Light from a LED source is created when power is applied in the junction between the electron source and sink. This power excites the electrons. As they return to steady state, photons of light are generated at distinct wavelengths (i.e., colors of light). The wavelengths produced through this process depend on the chemical composition of the die. For red and yellow signals, for example, the principal material used for LEDs is Aluminum, Indium, and Gallium Phosphate (AlInGaP). For blue and green LEDs, the principal substrate is Indium and Gallium Nitride (InGaN).

The die is then packaged in a form suitable for use in traffic signals. Typically a single die may be combined with a reflector to focus the light and a clear epoxy lens to protect the die. Anywhere from 150 to 600 of these "lamps" may be packaged in an array for use in a traffic signal head (Bullough 1998; Houghton 1994).

Because incandescent signals produce white light and must filter all colors other than the red, green, or yellow desired, incandescent light is an inherently inefficient source of light for traffic signal applications. In contrast, LEDs, which are essentially monochromatic, are quite an efficient source of traffic signal light. Additionally, incandescent bulbs produce considerable light outside of the visible spectrum, which is emitted in the signal head as heat. LEDs minimize both wasted light and heat. The first use of LEDs in a "luminaire" was in exit signs. Optical refinements in, and increased efficiencies of, LED exit signs may forecast a similar path for traffic signals.

Factors that Affect Performance

A range of factors affect the energy performance and longevity of an LED traffic signal. In addition to the number of lamps used to build the signal head (more lamps imply greater energy use), these include the color chemistry of the dies that make up the signal, the ambient temperature, and the signal controller circuitry.

- *Color chemistry*. The particular wavelength of light that a given die will emit depends on the chemistry of the electron-donating and electron-receiving layers of the die. The easiest light to produce is that with the longest wavelengths, such as red or orange. But the physics of producing shorter wavelengths of light, e.g., blue and blue-green, is more complex. In fact, it was not until 1992 that reliable blue-green dies could be produced. As a result, red and yellow LEDs tend to be slightly more efficient sources of light than green LEDs.

- *Use and temperature.* According to one manufacturer “LEDs don’t die, they simply fade away.” Initial studies indicate that LED traffic signal intensity degrades over time and with temperature. For certain color chemistries, the percentage of degradation of LED intensity over time is worse than for others. Initially red LEDs (based on Aluminum and Gallium Arsenide, AlGaAs) were used primarily in automotive applications where 10,000 hours of reliable light level is sufficient. For longer-lived applications, such as LED traffic signals, 25,000 to 50,000 hours of reliable light are required. This challenge has been met with new color chemistry (AlInGaP, mentioned above).

  Signal intensity also declines more rapidly with temperature (e.g., in hot climates). Proposed interim specifications for LED traffic signals developed by the Institute for Transportation Engineers define allowable degradation rates and most manufacturers are able to meet these either by incorporating heat sink materials and other features into the signal housing designs or through compensating controller circuitry that adjusts the drive current upwards over time and with heat to allow for greater light output as the performance of the LED array declines.

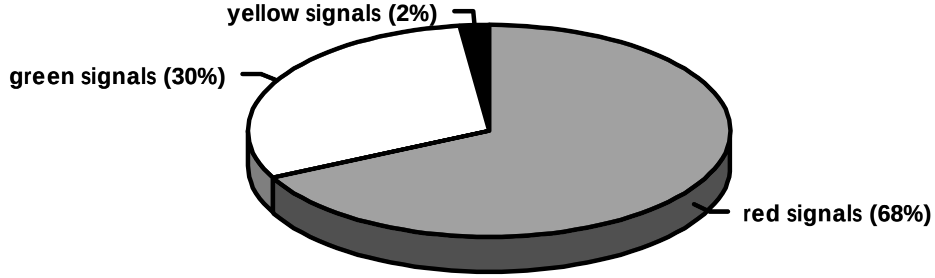
- *Traffic signal power supply and controller circuitry.* Power supply power factor (PF), total harmonic distortion (THD), and controller circuitry minimum drive current requirements for LED traffic signals currently contained in the ITE draft interim specification are considered by some to be unnecessary and may result in added system energy use.

National Energy Savings Potential

Approximately 260,000 signalized intersections mark the roadways of the United States (Mayer 1997). A typical intersection contains about 12 signals (Diese 1998; Mayer and Durgin 1998). For the purpose of analyzing energy savings, we have assumed 10 three-color ball signals and an average of 2.5 additional two-color (red and green) arrow signals per intersection (Durgin 1998). Under this assumption, 2.6 million each of red, green, and yellow ball indicators are in place, with approximately 650,000 each of red and green arrow indicators.

An estimated 3 billion kWh in electricity could be saved annually by replacing incandescent traffic signals with LED signals. Table 1 provides a breakdown of the estimated savings from different types of indicators as well as more details on the assumptions used in the analysis.Most of the savings (i.e., approximately 2 billion kWh or nearly 70 percent) could be derived from switching out red signals alone (see Figure 1). Typical red LED balls and arrows use 90 to 95 percent less power than the 150 W incandescent light source that they replace (e.g., 12-inch red balls require 15 W, saving 135 W and 12-inch arrows require 9 W, saving 141 W per signal).

More than 900 million kWh could be saved by replacing green incandescent signals with green LEDs. The savings are less, in part, because per unit signal savings for green LED signals are considerably less than for red signals. This is due largely to the fact that green signals have a lower duty factor than red signals. Red ball signals operate approximately 55 percent of the time, whereas green signals operate 42 percent of the time and yellow signals operate the remaining 3 percent. The discrepancy is even greater for arrows. Red arrows are on for about 90 percent of the time while green arrows are on about 10 percent of the time. Finally, retrofitting yellow incandescent bulbs with yellow signals can save an additional 61 million kWh.



In addition to offering substantial energy savings, LEDs last much longer than incandescent lamps (e.g., 5 to 10 years as opposed to 1 year), which has enabled many jurisdictions to reduce their maintenance schedules from every year to every other year, while avoiding replacement incandescent lamp costs (for the life of the LED) and garnering safety and liability benefits from reduced risk of signal outage. These issues are discussed more below within the context of the economics of LED traffic signals.

CURRENT ACTIVITY TO PROMOTE/DEVELOP LED TRAFFIC SIGNALS

As of April 1996, 25,000 signal heads in the United States had been retrofitted with LEDs (Mondre and O'Connell 1996). By the end of 1997, more than 150,000 LED traffic signals had been installed, and installations are anticipated to double this year (Evans 1998; Mayer and Durgin 1998). Virtually all installations have been retrofits of either red balls or arrows, although recently, a number of localities have begun to purchase and install green (and in a few cases yellow) traffic signals to capture the considerable maintenance benefits.

State departments of transportation and utilities have been leaders in getting LED traffic signals into the market. California Department of Transportation (Caltrans) and the Oregon Department of Transportation (ODOT) began researching the potential for applying LED traffic signals in the early 1990s. Several pilot projects have been completed in California and Oregon, and many jurisdictions in these states are now pursuing large-scale retrofits or complete changeovers to LED signals. Caltrans has announced its plans to switch all red signals under its control (i.e., 75,000 signal heads) completely to LEDs and has prepared and made publicly available its performance specification (in advance of a final national specification from the ITE).

The cities of Denver and Philadelphia were also early adopters of the technology. The city and county of Denver have fast-tracked installation of some 10,000 LED red balls and red arrows. Philadelphia is now planning a city-wide retrofit of its red signals to LEDs and is working with manufacturers to develop and test prototype three-color LED traffic signals. With funding from Public Technologies Incorporated, Philadelphia conducted an evaluation of its early retrofits and developed a purchasing specification that other regions including New York City and New Hampshire have drawn on in developing their LED traffic signal purchasing requirements.

The states of Florida, Ohio, Michigan, Minnesota, Nevada, New Hampshire, New York, New Jersey, and Texas and a host of municipalities have also specified LED traffic signals, primarily for a few pilot installations. And the New Hampshire Department of Transportation is reportedly also planning extensive retrofits of both red and green signals and has experimented with retrofits of all three colors. Given the trend in other regions of the country, the experience of these states and municipalities is likely to lead to broader installations of the technology. Highlights from states and municipalities around the country are presented below.

- The *city and county of Denver* has converted 10,000 intersections to red LEDs at a cost of approximately $1.7 million with an estimated annual savings of $360,000 in energy, labor, and materials.

- The *city of Philadelphia* is undergoing city-wide retrofits of 2,900 intersections to red LEDs. Total capital costs for the retrofits are estimated at $2.2 million. Annual power cost savings are estimated at nearly $1 million with additional cost savings of approximately $250,000 yearly from reduced relamping, fewer burnouts, reduced component loads, and reduced accident liability.

- *New York City* is retrofitting the 18,000 intersections in the borough of Queens at an estimated energy cost savings of $325,000 and a maintenance savings of $372,000. The New York City Department of Transportation is also currently assessing the feasibility of replacing all red and green traffic signals on Staten Island with LEDs.

- *Caltrans*, as noted above, ultimately plans to retrofit all of the red signals under its control. In its initial phase, Caltrans will convert 48,000 signals at a net savings, after accounting for all signal installation costs, of $4 million over four years. Maintenance savings, however, accounts for only about one-tenth of the total savings since the state's 60-day maintenance checks are required regardless of light source.

Some utilities, such as Pacific Gas and Electric (PG&E), Portland General Electric, Puget Power and Light, and Public Service Company of Colorado either had or currently have rebate programs in place for LED traffic signal retrofits. Other utilities and public power companies offer financing for LED signal retrofits. PG&E offers local governments financing for LED signal retrofits through its Energy Advantage program. Northern States Power plans to provide St. Paul with a zero-interest loan to finance LED retrofits in the city. The New York Power Authority (NYPA) provides New York City with low-cost financing (at NYPA's cost of capital, currently 4 percent) for installing red LEDs and enhanced-life green and yellow incandescent lamps in the borough of Queens. Finally, Northeast Utilities is financing LED retrofits in several Connecticut cities and Public Service Electric and Gas (PSE&G) is offering LED retrofit installation and maintenance services directly to customers in its territory. And Boston Edison Company has proposed a substantial LED traffic signal market transformation initiative to its utility commission.

KEY CHARACTERISTICS AND TRENDS IN THE TRAFFIC SIGNAL MARKET

Market Structure

The principal actors on the supply side of the market for traffic signals are the component suppliers (who supply the light source material or material packages, controls, and traffic signal housing), and the traffic signal manufacturers. For the purpose of examining the LED traffic signal market, we focus here on the source material suppliers/packagers and the traffic signal retrofit kit manufacturers.

Relatively few manufacturers supply the traffic signal market with LEDs. The key suppliers for red LEDs include Toshiba, Hewlett Packard and UEC (a division of a China semiconductor). And the primary suppliers of green LEDs are Nichia and Toyota Gosai, although Toyota Gosai has licensed its technology to several companies, including Hewlett Packard, Mitsui, and Siemens (Evans 1998).

The least costly LEDs to produce are the red LEDs. However, when first introduced for traffic signal applications in the early 1990s, a limited number of suppliers rendered the price of these die quite high. Since then, the demand for red LED traffic signals has grown, die chemistry has improved, several new die suppliers have entered the market with high-quality red LED products, and the price has dropped dramatically. Like the red LEDs, yellow LEDs were also relatively easy for manufacturers to produce but the intensity requirement of the ITE incandescent specification (considerably higher for yellow and green signals than for red signals) and their low duty factor has rendered them uneconomic when considered independently for traffic signals.

Green LEDs adequate to meet the color requirements of the ITE incandescent specification have proven quite difficult to produce. Early green LEDs were produced with silicon carbide and produced little light (E Source, Inc. 1997; Hochstein 1997). But in 1992, Nichia Corporation succeeded in combining Indium and Gallium Nitride (InGaN) to produce a broad spectrum blue-green die that both satisfied the ITE color requirements and increased light output relative to the older silicon carbide dies by two orders of magnitude (E Source 1997). Toyota Gosai, however, followed on its heels by producing a viable green die and as indicated above, has licensed its technology to several other suppliers. Hewlett Packard is now actively developing its own green die and anticipates that the price for green dies will decrease substantially over the next few years as they and other manufacturers bring new green dies to market (Evans 1998).

LED traffic signal manufacturers assemble packages of LEDs produced by die manufacturers and others into traffic signal retrofit kits. The LEDs are arranged in arrays or strings, which are fitted into a fixture, typically with a reflector, and connected to a power supply that transforms and rectifies alternating current (AC) to the direct current (DC) required by the LED signals. These retrofit kits are designed to easily fit into the housing for incandescent signals. Two traffic signal manufacturers, Dialight and Ecolux (Canada), are the dominant manufacturers of LED traffic signals, serving more than 80 percent of the market (Mayer and Durgin 1998). Several other manufacturers, including Precision Solar Controls, Electro-Techs (the first LED traffic signal manufacturer), and Relume Corporation, serve smaller market niches (Evans 1998).

On the demand side are equipment specifiers and purchasers, such as state department of transportation personnel, county and municipal energy office staff, traffic engineers, equipment installers, and maintenance staff. Typically, purchasing is in the purview of the state or local agencies, while installation and in some cases, maintenance may be out-sourced. New York City, for example, has out-sourced both equipment installation and service. Several Connecticut cities are working through Northeast Utilities for installation and on-going maintenance of their LED traffic signals.

In addition to these players, several other actors facilitate transactions in the traffic signal market. ITE, mentioned earlier, writes standards and specifications for vehicle control devices. The current standards by which incandescent traffic signals are specified were initially developed by the ITE in the 1930s. For the past several years, an ITE working group has been in the process of developing a specification for LED traffic signals, but a number of technical and political problems have plagued this process. An ITE specification for LED traffic signals could assuage the liability concerns of many state and local governments and pave the way to more rapid market transformation. A specification with lower intensity requirements for green and yellow signals, could render these signals more cost-effective and could make a reasonable-cost three-color signal a reality.

However, even in the absence of a final specification from the ITE, the market is being transformed in certain regions of the country. This phenomenon has been assisted by a number of states and localities that have written their own specifications for LED traffic signals (e.g., the states of Oregon and California, and the city of Philadelphia). Other states and municipalities have based their purchasing requirements largely on the early experience, testing, and specifications developed by these jurisdictions.

Finally, utilities appear to have stimulated the market for LED traffic signals in several regions. Public Service of Colorado provided rebates for and spearheaded Denver's major LED traffic signal retrofit. PG&E program managers, who ran an LED traffic signal rebate program from November 1996 through November 1997, feel that the rebates, have been instrumental in initiating market transformation in Northern California (Chetaitis 1998).

Alternative Light Sources

Since signalized intersections were first introduced, incandescent bulbs have been their principal light source, although other technologies have been tried. The most promising alternative to incandescent signals appears to be LED traffic signals. Other technologies, however, that have been considered and tested for use in traffic signals include cold cathode technology, electroluminescent panels, radio frequency induced fluorescence, and fiber optics.

- *Cold cathode*. Early experiments using cold cathode technology as a traffic signal light source were first tried around World War II (Tooze 1998). These were met with considerable power supply problems that led to failure. However, power supply improvements and a shift from non-solid state to solid state electronics have led some communities to reconsider cold cathode for traffic signals. Portland, Oregon, for example, is testing cold cathode technology as an alternative light source for the city's traffic signals. One manufacturer suggests that cold cathode traffic signals, with an estimated life of 10 to 17 years, could reduce power draws by 75 percent. Red signal retrofits in regions with relatively low electric rates (e.g., less than $0.05 per kWh) would pay for themselves in about 7 years (deMco Technologies 1998).

- *Electroluminescent panels*. Electroluminescent panels appear too dim for use in signals at this time (Johnson 1998). Additionally, they have a relatively short life and a history of production problems that limit their market readiness (E Source 1997).

- *Radio frequency induced fluorescent sources*. Radio frequency induced flourescent sources have been tried by at least one manufacturer. However, their energy performance is currently no better than fluorescent sources, which cannot compete with the energy savings offered by LED and potentially by cold cathode signals (E Source 1997).

- *Fiber optics.* Fiber optic pedestrian signals and red arrows have been tested and were found to be inadequate by Caltrans (Caltrans 1997).

At this point, LEDs are the most well-developed technology for the market, have a more mature market infrastructure, and are more cost-effective than other sources. Most manufacturers contacted expect this market to continue to grow and eventually for LED signals to be the norm in traffic control.

Economics of LED Traffic Signals

A typical incandescent bulb for traffic signals costs a jurisdiction approximately $2.50 to $3 to purchase. LED signal retrofit kits can be purchased at a significant premium. But the cost of red, green, and yellow LED retrofit kits varies considerably as a function of the number of die suppliers, market demand for the signal color, and intensity requirements. When first introduced in the early 1990s, red LED retrofit modules cost about $750 per head. In January 1993, just four years ago, red LED traffic signals cost about $350. As more die and signal manufacturers entered the market, the price dropped, and today improved red LED retrofit kits (i.e., with better dies, lensing, weather resistance, and controller circuitry) are available for less than $150 (and some are available for as little as $110). As a result, red LED balls pay for themselves in energy savings in about 2 to 5 years, depending on the electricity rate, and red arrows pay for themselves in an even shorter amount of time (less than 1.5 years) (see Table 2). Many communities that have retrofitted their red signals have also shifted from a yearly relamping schedule to a two-year relamping cycle, cutting their major maintenance expenditure in half.

So what about the green signals? Because the number of suppliers of green LEDs is low and the brightness requirements of the proposed ITE interim draft specification are fairly stringent (and therefore greater LED source material is required), the cost of green LED signals renders their purchase uneconomic in many regions, when considered alone. However, like red signals, the cost for green signals has come down in the few years since adequate green dies have been available and it is expected to decrease more as additional source material manufacturers enter the market. Currently, a typical 8" green ball costs about $375; one manufacturer of LED source material expects the price to decline within the next few years to approach that of reds (Evans 1998). When purchased in conjunction with red LEDs (assuming a future price of green

LEDs at $150), the cost of red and green ball retrofits will be recouped in about 3 to 6 years, while the cost of red and green arrow retrofits will be recovered in 2 to 4 years. Several localities are now beginning to install both red and green balls and arrows. Furthermore, communities replacing both green and red LEDs can save substantially more on maintenance than can communities who do red-only retrofits. In a study of the feasibility study of replacing red and green signals with LEDs in Staten Island, New York, the schedule for relamping is anticipated to shift from yearly to once every 5 to 7 years, potentially reducing maintenance costs by as much as 85 percent (Bordenaro 1998; Labruzzo 1998). Table 2 summarizes payback estimates and the cost of saved energy from retrofitting red, green, and both color balls and arrows.

Yellow signals cost considerably more than red signals, but similar to green signals, their high cost is the result of the high intensity requirements in the proposed ITE interim draft specification. Research currently being conducted by the National Cooperative Highway Research Program (NCHRP) on human visual requirements for viewing traffic signals is anticipated to lead to lower brightness requirements for green and yellow signals, and thus improve the economics of yellow signals and three-color signals. It is speculated that three-color signals, in addition to offering greater savings in energy and maintenance costs, may also reduce the cost of supporting traffic signals (because the housing is likely to be lighter in weight) and reduce the occupational hazard to installation and maintenance crews (because of the lower required voltages relative to incandescent lamps, e.g., 12 Volts instead of 120 Volts).

In estimating LED project costs and benefits, a number of states and localities have included routine maintenance cost savings, but other benefits have been more challenging to quantify, including reduced emergency maintenance costs and liability associated with less frequent lamp burn out. For example, red incandescent lamps are often changed out on an emergency basis, with overtime crews and associated overtime costs. LED traffic signals virtually eliminate this service cost in part because they are long-lived, but also because no imminent safety hazard is presented if one die or a series of die burn out. If need be, crews can replace the signal during normal working hours. This reduced risk to public safety represents an additional benefit of LED traffic signals and may, in time, result in reduced liability for jurisdictions with LED traffic signals. Also, some jurisdictions and utilities may find that LED retrofits can reduce the number of meters needed to meter intersections served by LED traffic signals, as well as the frequency of meter readings, thereby reducing the costs of operating or serving the intersection.

BARRIERS TO LED TRAFFIC SIGNAL PENETRATION

While early installations of LED traffic signals faced some problems with brightness degradation and early burnout, in general, retrofits with red LEDs have produced significant energy and maintenance cost savings without compromising performance relative to incandescent traffic signals. Despite their excellent performance in several regions of the country, several barriers hinder more rapid market penetration of red LED signal heads. These barriers and the high cost of green LEDs also limit the number of retrofits that include green LED signal heads. And new three-color fully integrated LED traffic signals are still in the early development stages.

Generally speaking, the key barriers to transforming the LED traffic signal market include:

- *Uncertainties about performance*. Lack of information, lack of time to research information (i.e., high information or search costs), mistrust of potentially biased data (e.g., where the key source of technical and performance information is manufacturers), and the absence of a national specification all contribute to concerns about the technology's performance.

- *Organizational practices and customs.* State and local policy development, procurement, and capital and operating budgeting processes, as well as limited capital availbility in many government agencies, limit investment in LED traffic signals.

- *High product costs.* High product costs (particularly for green LED retrofit kits) that result from inherently more costly technology, limited competition among source material manufacturers, and brightness standards (thought by many to be more stringent than necessary) hinder the LED traffic signals market.

Each are discussed below.

Uncertainties About Performance

Performance uncertainties signal a general lack of understanding and information about the proven technical performance and benefits of LED traffic signals. This, in turn, can give rise to unwarranted, but very real, concerns about liability risks. These concerns contribute to risk-minimizing behavior (i.e., choosing not to invest). Questions that arise include: Will the signals provide the appropriate amount level of intensity so that oncoming vehicles can see them under various driving conditions? Will they last as long as intended or will early failure result in catastrophe? In addition, jurisdictions may not feel confident in projected energy and other cost savings necessary to justify program costs. Many state and local governments lack data on the technology, lack the time and resources needed to gather the information, or view with some skepticism information provided by manufacturers. Absent reliable, accurate, and easy-to-use information, these jurisdictions will be reluctant to choose LED traffic signals.

Organizational Practices and Customs

Not all actors involved in state and local decisions to install LED traffic signals are in need of additional information on performance and savings, however. In a survey of traffic system engineers, one LED signal manufacturer found that this group, in particular, has a fairly high level of awareness about traffic signals. But city and county mangers and elected bodies who make policy and budgetary decisions about LED traffic signal projects are perceived to have less information available to them on the energy savings and other benefits, and more constraints imposed by procurement rules, budgetary processes, and others (see sidebar).

The ability of public officials to translate their willingness and interest in putting energy-efficient purchasing into practice is "directly related to the quality, specificity and comprehensiveness of the information easily available to them about energy-efficient products" (Raynolds 1997).

> **CHALLENGES OF GOVERNMENT PURCHASING**
>
> "[T]he purchasing process is strictly governed by rules, established procedures and defined decision criteria as well as perceived risks — of violating the rules, of wasting government money, and of appearing to improperly favor one vendor or product over another... Because the system is so rule driven, many participants are reluctant to depart from 'standard practice' unless they have been expressly charged or empowered to do so. The more money being spent, or the more visible the purchasing activity, the more this is true."
>
> Source: Raynolds 1997.

Many localities also face significant capital constraints, such that finding the capital for, or justifying, projects that pay back in any period greater than one budgetary cycle is challenging (Mayer and Durgin 1998). Futhermore, in many jurisdictions, capital expenditure and operating cost accounting is conducted by different departments or agencies. In these cases, the agency requiring budget authority to perform an LED installation and the agency benefitting from the energy savings differ. In Oakland, California, the transportation department requires the budget authority to perform installations (and thus generate energy savings). But the general services department pays the electric bills, so the general fund reaps the benefits of the energy cost savings (Raggio 1998). Unless capital and operating budgets are located under the control of the implementing department or an agreement is established to reward the implementing agency, there are disincentives within local government to perform LED retrofits and other capital intensive projects despite their potential lifecycle cost benefits.

High Product Costs

A number of factors contribute to the high costs faced by purchasers of LED traffic signals. First, LEDs are inherently more complex than are incandescent bulbs, and thus LED traffic signals cost more to produce. Second, there are relatively few manufacturers and limited competition among manufacturers of the source die used to construct LEDs. Third, the application for LEDs in traffic signals is relatively new, so some manufacturers (particularly the source die manufacturers) may be establishing prices at a level that allows them to recoup some of their research and development investment.

The market dynamics somewhat limit the influence that organizations pursuing market transformation strategies can have on LED traffic signal costs. For example, the cost of LED traffic signals appears to depend largely on prices established by a few die manufacturers who may be less responsive to traffic signal demand than to demand from other markets (i.e., the signage market). As a result, a number of traffic signal manufacturers consider activities such as bulk purchases relatively ineffective means of driving down prices in this market. Nonetheless, structural changes in the industry are proceeding fairly rapidly with a number of new players poised to enter the business of producing LED source material (particularly green LEDs). Also, ongoing research on traffic signal visual performance may demonstrate that current intensity requirements are higher than necessary for yellow and green signals, and hence drive up their cost.

STRATEGIES TO REDUCE LED TRAFFIC SIGNAL MARKET BARRIERS

The most appropriate strategies to address these barriers and to increase LED traffic signals market acceptance depend in part on the objectives of a given market transformation initiative. These can include increasing the rate of technology penetration of red LED traffic signals, increasing the use of both red and green signals (to take advantage of the greater maintenance savings), and developing and demonstrating fully integrated three-color LED traffic signals. These objectives can be pursued in tandem.

In general, broadening market acceptance of red LED traffic signals is likely to require a relatively modest effort focused on activities such as developing and disseminating case studies, deploying targeted demonstration projects, making financing more easily available, and to a lesser extent working with national and regional organizations on specification development (for those states and localities reluctant to proceed without a national specification).

Similarly, increasing the use of both red and green signals will require case studies, demonstrations, and other educational materials, as well as financial incentives and financing. In addition, more critical than for red signals alone will be facilitating specification development and working with or in parallel with organizations researching traffic signal brightness requirements.

Finally, making three-color signals a market reality can be facilitated by working with manufacturers to develop fully integrated three-color LED traffic signals, and with state and local governments to demonstrate their effectiveness. In addition to energy and maintenance savings (not much greater than two-color retrofits because of the low duty factor of yellow signals), some economies of scale are anticipated from system integration as are additional benefits, e.g., lighter weight, ease of use with newer traffic system controls, and reduced occupational hazard.

A number of the approaches needed to address barriers to red, red and green, and three-color LED traffic signal installations are cross-cutting. Below, we have broadly categorized them into three central strategies: (1) providing education/information; (2) offering incentives and financing; and (3) monitoring/facilitating specification development:

Provide Education/Information on LED Traffic Signals

When offered by a neutral third party, materials on LED traffic signals to inform and educate public officials can reduce their costs of acquiring information, reduce performance uncertainties, and generally improve their comfort level with the technology. This, in turn, may enable a shift away from “standard” purchasing practices. Because a champion for LED traffic signals can arise from virtually anywhere in a state or local government (e.g., traffic engineer, fiscal manager, and county executive), education needs to take place on multiple levels and include both general information on the benefits of LED traffic signals as well as technical performance data. Specific activities may include the following.

- *Develop, compile, and make available informational and educational materials for utilities; city, county, and state public officials; and traffic system engineers.*

  — A *national brochure* that can be used by regional market transformation groups, utilities, energy service businesses, and others seeking to educate state and local officials and staff about the benefits of LED traffic signals. The brochure can provide a space for another entity’s endorsement and traffic signal data specific to regional or local political subdivisions.

  — *Case studies* on experience with traffic signal retrofits, including information about the process used in developing pilot or full-scale retrofit programs, technical performance of LED signals over time (e.g., intensity over time and power quality), and energy and maintenance cost savings. These case studies should emphasize the most well-established programs, with the greatest experience. The case studies should also attempt to capture cases where different types of retrofits have been performed (e.g., red, red and green, and where available, three-color signal installations), cases in different regions of the country (Northeast, Southeast, Midwest, Southwest, and West), and cases in different types and sizes of jurisdictions (e.g., state, county, and city projects as well as rural and urban projects).

  — *Lifecycle cost calculators* that enable communities to estimate energy and maintenance costs savings as well as payback period given the communities’ electric rate structures. Using their own traffic system inputs, states and localities can get a sense for the potential energy savings, maintenance cost savings, and other benefits of LED traffic signals. Currently, Philadelphia makes a simple lifecycle calculator available on disk to those interested; the city also has a beta version of a more sophisticated, but easy-to-use, menu-driven tool for calculating lifecycle costs of traffic signal options. Pending U.S. Department of Energy (DOE) funding and product approval, this tool will be finalized and made available to the public.

- *Educate public officials and their staff about the availability of performance specifications (e.g., from California, Philadelphia, and Denver) and offer updates on the status of the ITE interim specification to partially address liability concerns.*

State and national specifications can considerably reduce a juridiction's liability concerns. Experience in California suggests that once the Caltrans specification was made publicly available, interest in pursuing LED traffic signal retrofits markedly increased (Chetitis 1998; Raggio 1998).

· *Fund demonstration projects and pilot projects to can give communities first-hand experience with LED traffic signals in the communities' systems and provide a proving ground for questions about performance.*

These may include pilot projects in high-profile jurisdictions where LED signals retrofits have not yet been tried to demonstrate performance of red and green signal retrofits as well as fully integrated three-color signals. These demonstrations should be well documented and provide material for new case studies.

A number of organizations and fora could facilitate distribution of educational materials and information. On the engineering side, traffic system engineers are fairly well informed and have a range of fora for discussing technical issues related to traffic signals (e.g., ITE and the American Association of State Highway and Transportation Officials [AASHTO]). Efforts should be made to coordinate with these organizations to exchange information and ensure that overlapping information is consistent with that being offered to city, county, and state management.

For public officials, appropriate fora for disseminating information on LED traffic signals may include newsletters, websites, and annual meetings (or relevant energy or environment subcommittee meetings) of key organizations. These may include the National Association of State Energy Officials (NASEO), the National Governors Association (NGA), the National Association of Counties (NACO), the International City/County Management Association (ICMA), and the National League of Cities (NLC), to name a few. Many of these organizations have regional or state chapters and affiliates that can be targeted by regional and local promotion efforts.

Offer Incentives and Financing for LED Retrofits

Providing rebates or financing (or offering information on how to access them) can open the door for jurisdictions to learn about the technology and see its performance demonstrated. In general, these incentives should be offered primarily on a limited basis as a financial carrot to expose communities to LED traffic signals. As jurisdictions get more comfortable with the technology, they tend to be more willing to fund it on their own. In some cases, however, longer-term financing is needed to overcome capital constraints.

A number of other approaches to encouraging LED traffic signal retrofits have also emerged. Through its Power Saving Partners (PSP) program, PG&E contracted with Electro-Test Incorporated (ETI), an energy services company, to deliver demand-side energy savings from measures including LED traffic signals installations.[1] ETI does not directly install or maintain signals but rather promotes LED retrofits as a cost-effective option for state and local jurisdictions and streamlines the process of getting PG&E incentive payments to participating localities (Raggio 1998).

Other companies, such as PSE&G, have take a more involved approach by arranging to directly purchase and install and/or maintain signals for jurisdictions within their service territories. Many utilities already have the equipment and trained personnel to install and service traffic signals. Under this approach, the jurisdiction does not have to pay outright for the signals and the utility-incurred costs of purchasing and installing the LED signals can be financed through the energy savings from the retrofits. This arrangement also provides a basis for the utility to develop long-term commitments with the jurisdiction for the provision of electric service (Mayer and Durgin 1998).

Monitor Progress on ITE Specification Development

Modest effort is warranted in tracking the development of the national specification and where stalled, identifying options to move the process forward. One key opportunity may exist with respect to research on LED brightness requirements.

Noted earlier, the NCHRP has been tasked with developing visibility performance requirements for traffic signals, independent of light source, based on human visibility needs.The focus of the requirements is on signal color and intensity. Signal intensity requirements in the current draft ITE interim specification are based on those for incandescent lamps and their lenses. When signal intensities were originally determined, red signal levels were established first because of their importance for safety; intensities for yellow and green signals were based on these findings. Since more light passes through green lenses than through red lenses and even more through yellow lenses, the brightness requirements for these sources is roughly two and four times as great as that for red signals, respectively.

Preliminary data from the NCHRP's research are expected to be available in 1998 in mid- to late summer and final data is anticipated a year later. Any specification that the ITE may agree upon prior to the study's completion will be revised contingent upon the results of the study. If manufacturer speculations are correct, this study will likely demonstrate that humans

[1] PG&E, in addition to providing incentives for LED retrofits through its PSP program, offered traffic signal rebates through March 1998 and currently provides equipment financing options for local governments through its Energy Advantage program.

require much lower intensities for green and yellow signals than currently called for in the specification for incandescent signals (Evans 1998; Mayer and Durgin 1998).

Information on how this process proceeds will be important for making mid-course decisions about the best strategies to pursue to effect sustainable shifts in the LED traffic signal market. If the ITE process experiences delays, energy efficiency advocates may want to voice their concerns in a concerted fashion. In the meantime, Pacific Gas & Electric Company is currently funding the Lighting Research Center to conduct a parallel effort to that of the NCHRP.

In the absence of a current ITE specification for LED traffic signals, some manufacturers suggest that regional purchasing specifications would help to facilitate the market for traffic signals. These could be written to reflect local climate conditions (e.g., the needs of communities in the Southwest would differ from those of New England). Jurisdictions that might be reluctant to purchase LED traffic signals independently might feel more confident participating in a regionally approved purchase. However, any decision to move forward on facilitating the development of a regional specification should be delayed until the summer of 1998 as it looks fairly promising that the ITE will be able to finalize its interim specification at that time.

CONCLUSIONS

LED traffic signals offer a significant energy, maintenance, and other cost savings opportunity to state and local governments. Since the signals were first introduced, the performance and reliability of LED traffic signals has come a long way, and the prices, particularly for red LEDs, have dropped dramatically. In addition, after a slow start, high-intensity green LED dies have been developed and green LED traffic signals that meet the proposed ITE interim specifications are currently being produced and installed in a number of jurisdictions. New market entrants are appearing in the green die market, which should put downward pressure on the price of green die. As a result, even greater energy and maintenance savings are achievable now than before. Finally, ongoing work on human visual requirements (the results of which are intended for use when the ITE specification is finalized) could result in lowered intensity recommendations for green and yellow LEDs, which would improve the economics of green retrofits and render three-color LED traffic signals a viable, cost-effective option.

Even in the absence of a current ITE specification, many communities have retroffited signals and are experiencing the significant energy savings, maintenance savings, increased safety, and other benefits of LED traffic signals. The market also appears to have considerable momentum. Last year the LED traffic signals market grew substantially and some manufacturers expect a doubling of the market size in the next year.

Nonetheless, lack of information, limited access to capital, high initial costs, and the lack of a current ITE specification limit more widespread market penetration of the technology. A number of national interventions are proposed in this report, with an emphasis on education, financing, and facilitating specification development, that could serve to reduce some of the barriers to broader market acceptance of LED traffic signals and facilitate full-scale market transformation.

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