

Digital Billboard Energy Use in California

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1 EXECUTIVE SUMMARY

1.1 REPORT DESCRIPTION

Billboards are outdoor signs typically large in size (14 feet by 48 feet to as large as 20 feet by 60 feet) and located along highways and busy surface streets. Traditional or “static” signs are comprised of paper panels lit at night with HID, fluorescent, or LED flood lamps. Digital billboards (DBBs), on the other hand, are comprised of hundreds of thousands of LEDs that display pixelated content on a continual basis. The main appeal of DBBs is that they allow for dynamic, bright, eye-catching advertisements that can notify drivers of targeted opportunities or real-time information and alerts. Unlike traditional static billboards, advertisements on DBBs can change easily and frequently, and can be tailored to the season, day of the week, time of day, or even to the minute.

DBB sales and installations in the United States have increased dramatically over the past decade. The rise in DBB sales is partly driven by the significant increase in revenue generated by these products over static billboards, as owners of DBBs can sell to several different advertisers simultaneously in a given month, compared to static billboards which only display one advertisement at a time and therefore can only sell space to one advertiser at a time.

Since DBBs are comprised of hundreds of thousands of power consuming LEDs, most of which are illuminated 24 hours a day, it is important to better understand the significant energy impacts of DBBs in California. Previous reports studying the energy use of DBBs present up to a six-fold difference in annual energy use (AEU), ranging from around 50,000 to over 300,000 kilowatt-hours per year, among equipment from different manufacturers installed around the country. However, DBB efficiency has improved as LED technology has matured, and today, annual energy use of new products is likely to be on the lower end of that range. Nevertheless, even among products manufactured today, there is a large range in performance between different manufacturers. Understanding what accounts for this wide variation in energy use, as well as identifying strategies to improve the overall efficiency of DBBs, will be examined in this report.

To characterize the energy use of DBBs for this report, information was obtained from primary and secondary sources to understand the basics of the technology, major market actors, installation trends, and market drivers, focusing on California when appropriate. Primary research included interviews with four out of the five major DBB manufacturers in the U.S., as well as one of the largest outdoor advertising companies in California. Secondary research was comprised of reviewing existing studies, news articles, and information from manufacturer and sign owner websites.

1.2 SUMMARY OF FINDINGS

DBB are comprised of LEDs, power supplies, cooling systems, lighting controls, and a computer, with LEDs being the largest contributor to a DBB’s power draw. As presented in previous reports, there is a wide range in the energy use of DBBs installed in the field, particularly when considering that older generation DBBs were built with less efficacious LEDs. Display brightness levels and image content are other variables beyond LED quality and efficacy that significantly affect the energy consumption of DBBs. Other strategies to reduce the overall energy use of a DBB include implementation of brightness control features that alter the brightness depending on the ambient light conditions, more efficient power supplies, and smarter and less energy intensive cooling strategies.

Through our research it became clear that energy measurement methods and references to energy consumption are not uniform. In this report, we outline the different metrics commonly used to characterize DBB energy use and propose a possible method for standardizing energy consumption reporting based on area and brightness levels. Incorporating some key assumptions about brightness levels, operating conditions, size, and display content, we calculated a typical, current generation DBB (14 feet by 48 feet) to use between **29,000** and **94,000 kilowatt-hours per year**. Based on our estimate of 250 to 300 DBBs installed in California, this corresponds to a range in statewide energy use of between **7 and 28 gigawatt-hours per year**, with a potential to increase significantly based on increased installations.

By focusing on the two energy saving measures that offer the greatest potential, high quality LEDs and tighter brightness control settings, we estimate that power reductions of up to 85% are possible, between the best and worst products. This translates to potential annual energy savings of around **80 megawatt-hours per sign**, or up to **1.36 gigawatt-hours savings per year** for the installed base of DBBs in California, based product performance data provided by manufacturers.

These estimates relied on several assumptions that could be refined through additional research. In order to more accurately characterize DBB energy use, the following future research opportunities are outlined at the end of the report: field monitoring, teardown analysis, utility data analysis, cost analysis, scope expansion to cover on-premise signs, and test procedure development.

2 INTRODUCTION

Billboards are large outdoor signs commonly used for advertising purposes along busy surface streets and highways. Though billboards have historically consisted of static signs externally lit by flood lamps, with the recent advancement of Light Emitting Diodes (LEDs) and electronic display technology, there has been a growing trend towards digital billboard (DBB) advertising.

The outdoor advertising sector began widely adopting digital technology over the past decade. The Outdoor Advertising Association of America (OAAA), the major industry trade organization representing the outdoor advertising industry, estimates that today there are roughly 4,900 digital billboards nationwide (OAAA 2014). In California, the emergence of DBBs is evident in most of the major thoroughfares, such as in and around Los Angeles, Sacramento, and San Francisco.

The main appeal of DBBs is that they allow advertisements to be dynamic. Unlike traditional static billboards, advertisements on DBBs can change within seconds and messages can be tailored to the season, time of day, or even to the minute. For example, local traffic conditions, AMBER Alerts, police or FBI searches, weather reports, special events, and holiday weekend sales can be displayed at the appropriate times, as message content is managed remotely through a networked computer.

DBBs display illuminated sign content 24 hours a day through the use of LEDs and a computer that receives images remotely via the Internet. DBBs are also equipped with lighting sensors and controls to adjust brightness based on ambient light conditions. Given that DBBs are comprised of hundreds of thousands of energy drawing LEDs and operate 24 hours a day, with particularly heavy energy needs during peak demand times when ambient lighting from sunlight is the brightest, it is important to understand the energy use of a DBB.

A commonly cited report entitled, "Illuminating the Issues: Digital Signage and Philadelphia's Green Future," attempts to characterize the energy use of DBBs (Young 2010). The report states that there may be up to a six-fold difference in energy use among DBBs from different manufacturers, ranging from around 50,000 to over 300,000 kilowatt-hours (kWh), as shown in Figure 1 below, though the data presented in the report are not clearly documented. Discussions with manufacturers and research conducted in support of this study indicate that while there is a significant range in performance among DBBs installed in the field, products installed today are likely at the lower end of the annual energy use range presented in the Young study, as LED efficiency has improved dramatically over the past several years.

In this report, we present an overview of current DBB technology and characterize the market for these products in California. Additionally, we look deeper into understanding the wide range of reported energy usage for DBBs in order to assess the statewide energy savings opportunities. Information and data were collected through numerous interviews and ongoing dialog with DBB manufacturers and sign owners and through Internet-based research.

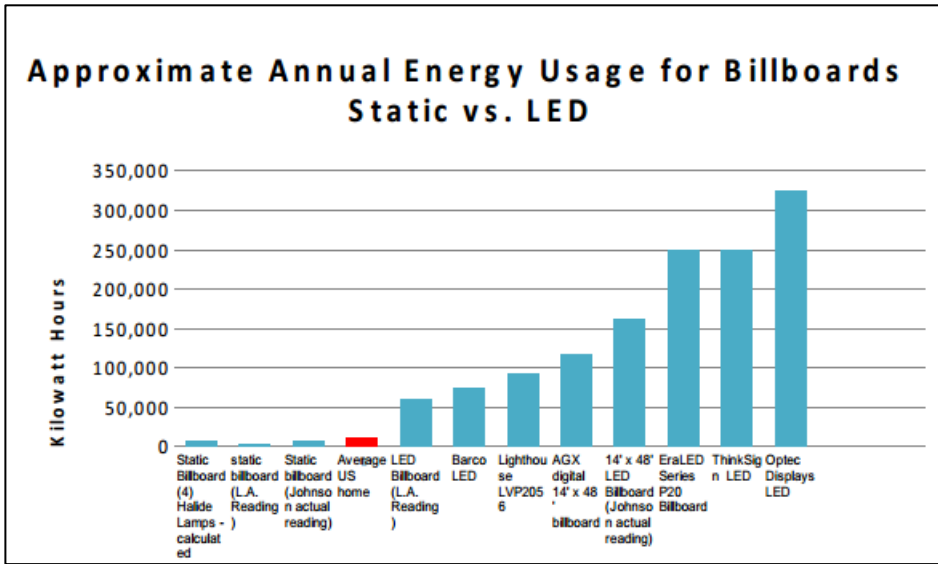


FIGURE 1. APPROXIMATE ANNUAL ENERGY USE OF STATIC AND DIGITAL BILLBOARDS

SOURCE: YOUNG 2010

2.1 SCOPE OF STUDY

Though different applications of digital signage tend to employ very similar technology, the focus of this study is on DBBs. As such, it is important to clarify the distinction between DBBs and other types of digital signage. Billboards are classified as “off-premise” signs typically large in size and located along interstates, highways and busy surface streets. Conversely, “on-premise” or “accessory” signs are those installed on a business’ property. Figure 2 provides examples of both types of signage. Though there are significantly more on-premise digital signs in existence than DBBs, this study focuses only on DBBs because these signs are more standard in size and application and are a good introduction into understanding the technology in the field.

Since the technology behind DBBs and on-premise digital signs are similar, many of the technological issues presented in this report can be applied to on-premise signs as well. We estimate the overall market size of on-premise signs is significant; further research is necessary to accurately characterize the market and energy savings potential of on-premise signs.



FIGURE 2. DIGITAL BILLBOARD (LEFT) AND ON-PREMISE DIGITAL SIGN (RIGHT)

SOURCE: GOOGLE IMAGES

2.2 DATA COLLECTION METHODS

To characterize the energy use of DBBs, data and information were obtained from primary and secondary sources. Primary research included interviews with four out of the five major DBB manufacturers in the United States (U.S.), as well as one of the largest outdoor advertising companies (sign owners) in California. Outreach activities consisted of multiple phone conversations, email correspondence, and in-person interviews, based on the questionnaires provided in Appendices A and B.

Secondary research was comprised of reviewing existing studies, news articles, and information retrieved from manufacturer and sign owner websites. This included a literature review of existing DBB studies to provide an overview of the market for DBBs, both in the U.S. and California, identify the major actors, and supplement the information or data provided by manufacturers and sign owners.

3 TECHNOLOGY DESCRIPTION

The term *billboard* is a generic classification referring to several types of outdoor signs. The most common forms are bulletins and posters. Bulletins are most commonly 14 feet by 48 feet (14' x 48') in size but can be as large as 20' x 60'. These very large signs are found in high-density locations and along highways. Posters are smaller (12' x 24', 11' x 22') and usually located alongside surface streets in urban areas. Though manufacturers can also build to any dimensions specified by the customer, these custom orders are not as frequent as orders for standard billboard sizes. For the purposes of this study, we only focus on the energy use of standard-sized 14' x 48' billboards.

One way in which DBBs differ from traditional static signs is in the manner in which the sign content is displayed. Traditional static signs are comprised of paper panels lit at night with high intensity discharge (HID) lamps, fluorescent, or LED flood lamps. DBBs, on the other hand, are comprised of hundreds of thousands of LEDs that display pixelated content on a continual basis, where the pixels themselves are the light sources. This report section presents the components that comprise DBBs.

3.1 PRODUCT COMPONENTS

A DBB is comprised of LEDs, power supplies, cooling systems, lighting controls, and a computer. Each of these components is described in detail in the following sections.

3.1.1 LEDs

A typical DBB display is composed of hundreds of thousands of pixels, each of which typically contains 3 or 4 LEDs. Though not as common, a pixel can also be a single diode. The total number of pixels in a display is determined by the pixel pitch, which is defined as the distance, in millimeters, of center-to-center spacing between adjacent pixels. Pixel pitch plays a large role in the sign's image quality or resolution (i.e. the total number of pixels in a display). Figure 3 provides an illustration of how three different color LEDs are combined to produce a single pixel, and how pixel pitch is measured.

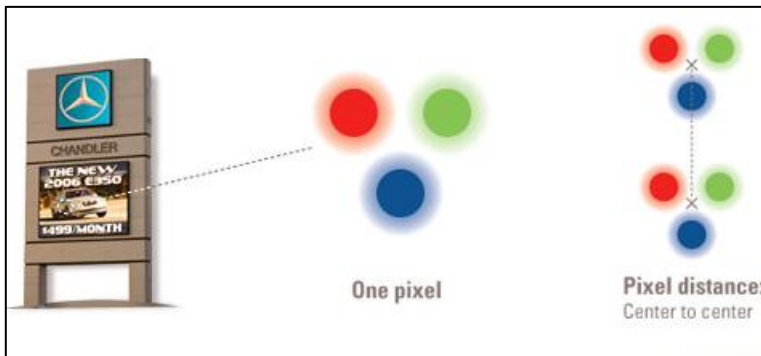


FIGURE 3. PIXELS AND PIXEL PITCH

SOURCE: YESCO ELECTRONICS WEBSITE

A sign that has more pixels, or smaller pixel pitch, will yield higher resolution and typically better picture quality. *LED density*, defined as the total number of LEDs in one square meter, is a related metric commonly used to convey the display performance of a DBB. It is calculated by multiplying the number of pixels per square meter by the number of LED per pixel. Pixel pitch and/or LED density are the key factors in determining the quality of resolution and achievable display brightness.

According to manufacturers, a pixel pitch of 19 or 20 millimeters (mm) has traditionally been the standard resolution for DBBs, but recent trends suggest that higher density pixel pitches, such as 16 mm, are becoming more popular. These displays contain roughly 25 percent more pixels compared to 19 mm or 20 mm displays, which allow for greater resolution resulting in a crisper, clearer image. Since bulletins are frequently located alongside highways, and therefore typically found at greater viewing distances, 19mm or 20 mm resolutions are still considered acceptable.

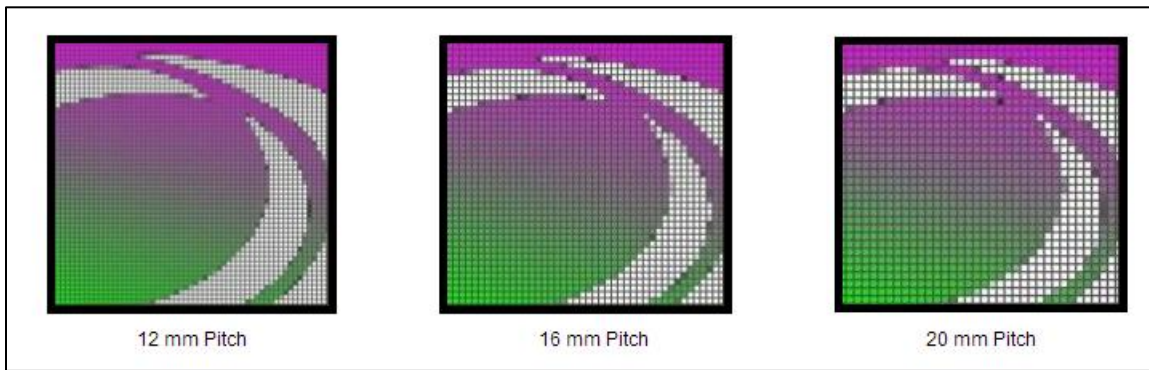


FIGURE 4. EXAMPLES OF VARIATIONS IN PIXEL PITCH

SOURCE: OPTEC MEDIA WEBSITE

As is typical in the LED industry, the expected lifetime of the sign is often tied to the quality of the LEDs used, as higher quality LEDs will remain brighter for a longer period of time. Current generation high quality LEDs typically exhibit lumen maintenance values of 75,000 to 100,000 hours or more, which translates into roughly 8 to 11 years of useful life.¹ Accordingly, DBB manufacturers typically quote lifetimes on the low end of this spectrum, at around 7 to 8 years. It should be noted that LED lumen maintenance is not a true indication of DBB lifetime, as it does not take into consideration actual component failure rates that may cause the system to fail before the LEDs reach their tested lumen maintenance values.

3.1.2 Power Supply

As with LED light sources in any application, power supplies are used to convert alternating current line voltage into a constant current that is required to drive LEDs. By regulating the current flow into the LEDs, the power supply is able to manage the power consumption and thermal conditions of the LEDs, which in turn determines the level of light output.

3.1.3 Cooling System

DBBs typically come equipped with fans or mechanical cooling systems to keep the LEDs, computer, and power supplies cool, especially on hot days. Since LEDs degrade faster when operating at higher heat, a proper cooling system is crucial for ensuring long lifetime of the display. Most cooling systems are equipped with automatic controls to only turn on when the display reaches a certain temperature.

3.1.4 Lighting Controls

All DBBs are installed with auto-dimming and brightness controls as a mechanism for determining the brightness of the display. Many displays can automatically dim to a specified percentage of brightness at a certain time of day (e.g. sunset), as determined by an astronomical time clock.

¹ Lumen maintenance is a measure of how much light output remains at some point in time after the light source has been operating. For LEDs, lumen maintenance is typically expressed as the number of hours before the light output has degraded to 70% of initial light output.

Alternatively, a photocell or light sensor can be used to determine ambient light levels, which are used by a controller to set the brightness level of the sign accordingly. These two control methods can also be used in combination, where the astronomical time clock provides backup in case of photocell failure or error.

3.1.5 Computer

Another primary component of a DBB is the computer, which holds the content that is presented through the sign's display. The computer can typically be managed remotely from the Internet and mounted behind the screen, in an easily accessible location for maintenance purposes.

3.2 OTHER TECHNOLOGIES: SOLAR

Some DBBs are powered through the use of solar panels and photovoltaic solar modules. In certain cases, these arrays rotate to follow the sun's path through the day, provide DBB power requirements during daylight hours, and upload any surplus power to the grid. In Arizona, G&S Electric Inc., a solar electric contractor, has installed off-grid photovoltaic DBBs similar to off-grid cell phone towers. It is important to note that we have not found any evidence that these technologies are currently being employed to a large extent with DBBs installed in California.

The major drawbacks of solar-powered DBBs are the fact they are location- and weather-dependent. Harvesting and processing solar energy is relatively inefficient (Aust 2007). Considering the energy savings benefits under those conversion rates, the initial installation and ongoing maintenance costs for solar-powered DBBs can be prohibitive for sign owners.

4 CALIFORNIA MARKET CHARACTERISTICS

4.1 INSTALLED STOCK

The majority of DBBs in California are located in large metropolitan areas and alongside highways. The OAAA estimates that there are 4,900 DBBs installed nationwide. Using the percent of total U.S. road mileage in California as a proxy, we calculate approximately 200 to 400 DBBs are installed in California.² We have refined this estimate to somewhere between 250 and 300 DBBs across the state based on information provided through outreach with the major outdoor advertising companies that have DBBs in the following markets: Greater Los Angeles, Inland Empire, Riverside, San Francisco Bay Area, Sacramento, Bakersfield, and Palm Springs.

Though the total number of DBBs currently installed in California is still relatively low, there is significant potential for the DBB stock to increase significantly in the near future. As an upper bound, estimates for the total number of static billboards in the U.S. range from around 365,000 (by the OAAA) to around 450,000 by a Congressional Research Service study in 1991 (Scenic America). Using the fraction of urban roads in the U.S. that are located in California, this translates to up to 35,000 static billboards in California (see Figure 5). Though the stated goal of DBB manufacturers to convert all static billboards to digital may be optimistic given some jurisdictions require tradeoffs of multiple static signs in place of a single DBB installation, conservatively assuming that just half of

² According to the U.S. Census Bureau, approximately 4% of all roads, 5% of interstate freeways, and 8% of urban roads in the U.S. are located in California (<http://www.census.gov/compendia/statab/2012/tables/12s1089.pdf>).

existing static signs in California are someday converted to digital, there may ultimately be over 17,000 DBBs in California.

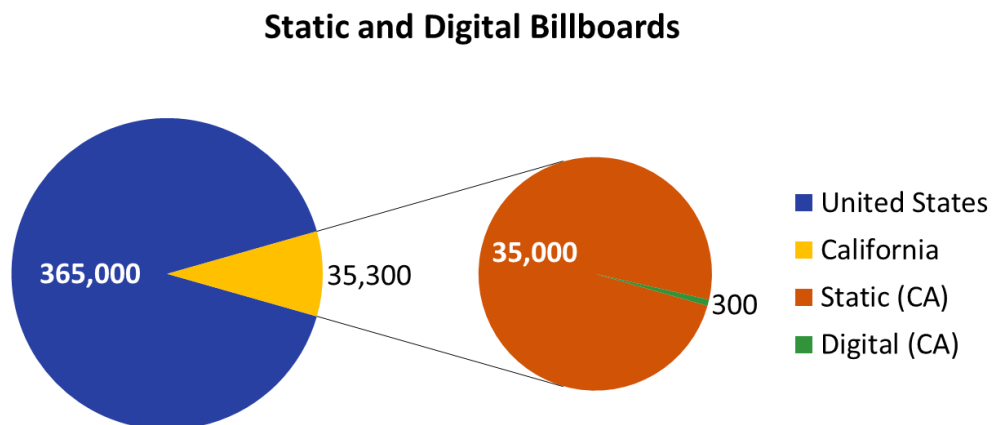


FIGURE 5. ESTIMATES OF STATIC AND DIGITAL BILLBOARDS IN THE U.S. AND CALIFORNIA

4.2 KEY MARKET ACTORS

The DBB market is comprised of manufacturers of digital displays, sign owners (i.e. outdoor advertising companies), and advertisers. Secondary actors are the component manufacturers, trade associations, installation contractors, and local municipalities.

There are several companies in the U.S. that manufacture DBBs. The largest manufacturers in the U.S. market are Watchfire Digital Outdoor, Optec Displays, Yesco Electronics, Daktronics, and Formetco. While most of these companies have domestic factories, some assemble their products in Asia. There are also foreign companies that sell DBBs in the U.S. and manufacture their products in Asia. In addition, most manufacturers source components (e.g. LEDs, computers, power supplies) for their DBBs from overseas. Incidentally, many of these companies purchase LEDs from the same LED manufacturers, which are also located in Asia. The components are shipped to the manufacturers where they are assembled into DBBs and calibrated for brightness before being disassembled and shipped in modular pieces to the customer for installation.

The customer base for the outdoor advertising market is comprised of a relatively small number of sign owners. The largest companies are Lamar Outdoor, CBS Outdoor, and Clear Channel Outdoor. All three of these companies operate DBBs in California as well as nationally, though they do not all operate within the same markets in the same geographical areas. As there are also many smaller outdoor advertising companies and individual sign owners, the aforementioned companies comprise the vast majority of the market.

Other DBB market actors include: 1) businesses and advertising firms that lease advertising space from sign owners and 2) local municipalities. The former group drives the demand for digital advertising and is the motivation for sign owners to include digital billboards as part of their sign stock. The latter group plays a role in accruing revenue from DBBs in the form of permits, taxes, and property leases. Many municipalities are amenable to DBBs for the higher revenue potential of these signs over static billboards. However, as described in Section 4 (Policy Drivers), some municipalities

are not as open to the expansion to digital and have ordinances in place to either set a limit on or prevent the proliferation of DBBs. Figure 5 diagrams the major market actors for DBBs.

4.3 DISTRIBUTION CHANNEL

Product components are shipped to DBB factories, most of which are based in the U.S. Once an order is placed, the sign is assembled and calibrated, then disassembled and shipped to the customer.

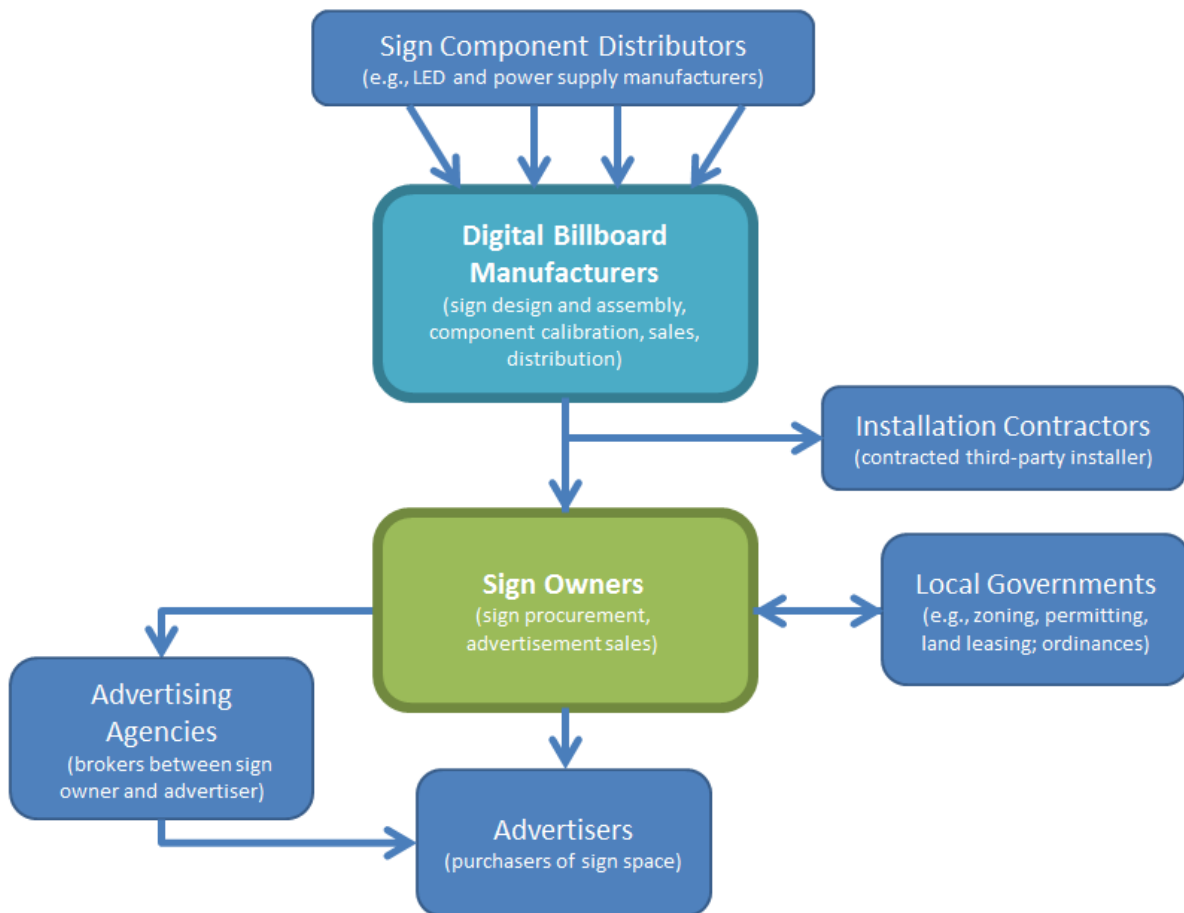


FIGURE 6. DIGITAL BILLBOARD MARKET ACTORS

Different manufacturers have different methods for building and installing DBBs. While some use smaller display modules that can be assembled in various configurations, the majority of manufacturers ship DBBs to customers in 2 or 3 large pieces. Sign owners are then responsible for installing the display at the site, which usually involves hiring general contractors. The installation contractors oversee the installation process and use heavy equipment to affix the digital display atop a sign structure (i.e. pole). Contractors also ensure that the necessary power and data connections are made. Many DBB companies will send technicians to also oversee the process and to calibrate the sign's brightness controls after it has been installed.



FIGURE 5 DIGITAL BILLBOARD INSTALLATION ON EAST SIDE OF SAN FRANCISCO - OAKLAND BAY BRIDGE

SOURCE: GOOGLE IMAGES

4.4 SALES AND INSTALLATION TRENDS

According to manufacturers, DBB sales increased rapidly through the early 2000s with a peak around 2009. The rise in DBB sales is partly driven by the significant increase in revenue generated by these products over static billboards. According to some reports, each digital sign can produce \$14,000 a month in revenue, from multiple advertisers, compared with \$1,000 to \$2,000 for traditional static billboards, which can serve only one advertiser at a time (Goldstein 2008).

Since the peak in 2009, DBB sales have slowed somewhat. Some manufacturers associate the slower rate of growth post-2009 with the economic downturn, but the regulatory landscape for outdoor advertising may also be another factor. For example, the permitting process for installing DBBs can be burdensome and some municipalities have set a cap or ban on DBBs. Despite the growing trend toward DBBs, manufacturers and sign owners agree that state and local policies play a significant role in the installations of the DBBs. More information on regulatory issues relating to DBB installation is presented in Section 4 (Policy Drivers) of this report.

Though state and local policies have begun to curtail the growth of DBB sales, lower costs in recent years makes DBBs an even better investment than before for sign owners. According to manufacturers interviewed, the cost of a new DBB has fallen more than half over the past few years, with prices now ranging from \$160,000 to \$185,000 for a 14' x 48' DBB.

4.5 POLICY DRIVERS

The regulatory landscape for DBBs is focused mainly on issues of safety (i.e. brightness, moving images) and aesthetics. Federal, state, and local jurisdictions regulate billboards based on size, location, brightness levels, and display times, with local ordinances often being stricter than federal or state regulations. In addition, the outdoor advertising industry self-regulates through the OAAA Code of Industry Principles. For DBBs, the principles are centered primarily on sign brightness as a response to complaints regarding motorist safety and light pollution. There are no regulations pertaining to the energy use of billboards.

Billboards were first regulated for their aesthetic and safety impacts through the Federal Highway Beautification Act (HBA), Public Law 89-285, signed by President Lyndon B. Johnson on October 22, 1965. The HBA is intended to protect natural and scenic beauty and to promote the safety and recreational value of public travel along federal-aid highways. It requires states to maintain "effective control" of outdoor advertising or else be subject to a loss of 10% of their Federal-aid highway funds. Section 131(d) acknowledges that, "States shall have full authority under their own zoning laws to zone areas for commercial or industrial purposes, and the actions of the States in this regard, will be accepted for the purposes of this Act" (FHWA 2014). Each state is required to enter into a mandatory agreement with the federal government by signing a Federal State Agreement (FSA) that sets forth sign controls in commercial and industrial areas based on customary usage.

Since its passage in 1965, numerous amendments to the HBA and guidance documents have been published by the Federal Highway Administration (FHWA) to provide clarity and to keep the legislation up to date with new technologies and advertising methods. In the past as outdoor digital advertising technology was new, local and state officials worried that the signs could pose a traffic hazard and, therefore, be unlawful. The FHWA has ruled that digital billboards do not violate Federal law. One of the most recent FHWA guidance documents, published in 2007, offers the following approved ranges of acceptability for changeable digital displays:

- Duration of each display is generally between 4 and 10 seconds. Eight seconds is recommended.
- Transition between messages is generally between 1 and 4 seconds. One to two seconds is recommended.
- Brightness in response to changes in light levels so that the signs are not unreasonably bright for the safety of the motoring public.
- Spacing between such signs not less than minimum spacing requirements for signs under the FSA, or greater if determined appropriate to ensure the safety of the motoring public.
- Locations where allowed for signs under the FSA except such locations where determined inappropriate to ensure safety of the motoring public.
- Prior FHWA guidance noted that changeable message signs were unlawful in states where the FSA bars signs with "intermittent," "flashing" or "moving" lights (FHWA 2014).

The guidance provided by the 2007 HBA amendments has a significant influence on state regulations of digital signage with each state basing its outdoor advertising regulations on the HBA.

4.5.1 California

California regulates outdoor advertising through the California Code of Regulations. Each year, the California Department of Transportation (CalTrans) publishes the "Outdoor Advertising Act and Regulations," which is an informal document that lists the current statutes and regulations governing outdoor advertising in California (CalTrans 2014). According to the 2014 Edition, the

state gives local jurisdictions (e.g. counties and cities) the authority to designate the districts or zones in which billboards can be placed or prohibited as part of a county land or zoning ordinance. This means local jurisdictions make the sole determination on whether DBBs are allowed, and if so, how many can exist in a certain area. This is done through the permitting process. Though sign owners must obtain a permit at the state level, they must also do so at the local level, which can be very time-intensive. According to manufacturers and sign owners, the local permitting process can take up to two years and can be prohibitive for smaller companies or independent sign owners. Some manufactures have a local government relations department or liaison that assists customers in navigating the permitting process.

Many jurisdictions in California have a limit or cap on the number of DBBs that can be installed. For example, the City of Sacramento requires a number of static signs to be taken down in place one DBB being erected. The City of Los Angeles pursued this approach in 2006 when attempting to settle a law suit with Clear Channel Outdoor and CBS Outdoor. They agreed to allow the companies to convert as many as 840 static billboards to digital as a way to sidestep a moratorium on digital installations that the City passed in 2002 (i.e. the cause of the law suit). However, in 2013 the Los Angeles Superior Court directed Clear Channel Outdoor and CBS Outdoor to turn off 82 DBBs and 13 DBBs, respectively, ruling that the permits issued to the companies by the City of Los Angeles under the 2006 agreement were invalid. Other cities have self-imposed bans or moratoriums on DBB installations. The City of San Diego, for example, does not allow any DBBs within city boundaries.

Conversely, many financially-strapped municipalities are welcoming the installation of DBBs as a source of revenue generated from permitting, franchise, and property leasing fees for operating within municipal boundaries. Though these jurisdictions might be permitting or considering permitting DBBs, there are still strict guidelines and policies on the number and location of DBBs.

5 ENERGY USAGE

Though DBBs use LEDs, which are more efficient than other light sources, they require hundreds of thousands of LEDs in order to display the image. Further, DBBs consume energy 24 hours a day, unlike static displays which typically only use electricity for lighting at night. Moreover, DBBs consume the most amount of energy in daylight hours when ambient lighting conditions are brightest. During maximum daily peak demand for electricity, one DBB can contribute more to peak loading compared to other energy-using equipment since a DBB is brighter and using its cooling system more frequently during peak hours. Compared to static billboards, which typically use HID, fluorescent, or LED flood lights that draw several hundred watts of power, DBBs require orders of magnitude more power, on the range of tens of thousands of watts at full brightness. Additional details around DBB energy use is presented in the following report sections.

Manufacturers claim that billboard energy use has improved significantly over the past several years. A 2011 OAAA study by the Louis Berger Group³ reported that the energy consumption of 14' x 48' digital bulletins dropped 61% since 2007, while the energy consumption of 12' x 24' digital posters declined 40% over the same period. They attributed the reduction in energy use to a number

³ Louis Berger Group is an organization that lobbies for the protection of business owners while promoting strategic communications.

of innovations, including controls that reduce brightness at night and improved cooling technology (OAAA 2011). We were unable to verify the accuracy of those claims because the study is no longer publicly-available.⁴

Though energy efficiency is a key selling point for manufacturers, there is very little publicly available data on DBB energy use. According to the 2010 Scenic America⁵ study on the energy use of digital signs across the country, the annual energy use of a DBB can be anywhere from 50 to 320 megawatt-hours (MWh) (Young 2010). The values presented in the study are not well-sourced and in some cases it is not clear if they are comparing billboards of similar size. Additionally, the energy measurement methods are not likely uniform, since there are no standardized methods for measuring or reporting the energy use of DBBs. These factors could all contribute to the wide variation in energy use presented in the Scenic America study.

Based on conversations with manufacturers, such a range in energy use may actually be fairly representative of the equipment installed in the field, considering that older generation DBBs were built with less efficacious LEDs when compared to LEDs currently available on the market. It has been well documented that LED technology has matured rapidly in recent years. Manufacturers widely agree that the DBBs that are produced and installed today require significantly less energy (between 50 to 70 percent less, in some cases) than those produced only a few years ago (Camillo 2013; Daktronics 2014). The following sections discuss in detail the metrics commonly used by the DBB industry to characterize energy use, magnitude of statewide energy use, options for improving energy efficiency, and potential methods for standardizing energy consumption testing and reporting.

5.1 ENERGY METRICS

Accurately assessing and comparing the energy use of various DBBs is challenging given that to-date there is no industry standard method of measuring or referencing the energy consumption of this equipment. Different metrics are commonly cited by manufacturers to describe DBB energy use. For example, some manufacturers report watts per pixel (W/pixel) or watts per square foot (W/sq ft). While per pixel efficiency including any power supply/driver losses may be the fundamental building block of total sign energy use, data are not readily available in product literature provided by manufacturers. Many manufacturers prefer to present energy use in terms of the whole sign, which makes fair comparisons between different products very challenging, as this metric (i.e. W/sign) does not factor in important considerations such as the billboard's brightness or pixel density. Table 1 presents a list of energy use metrics commonly used in the DBB industry and the range of values we have found through our research and conversations with manufacturers.

⁴ OAAA membership is required to view the study by the Louis Berger Group.

⁵ Scenic America is a nonprofit advocacy organization and the only national group solely dedicated to removing visual blight and preserving and enhancing the scenic character of America's communities and countryside.

TABLE 1. COMMON METRICS USED TO DESCRIBE THE ENERGY USE OF DBBS

Common DBB Metrics	Range of Reported Values ¹
Watts per pixel	0.14 – 0.2
Watts per square foot	16 – 20
Watts per sign	~15,000

¹ Range of values provided by manufacturer interviews and available product literature.

Several assumptions are required before this information can be used to fairly compare the energy use of equipment among manufacturers. First, it is crucial to account for differences in pixel pitch and pixel configuration. Therefore, for a more accurate comparison of the energy use of displays made by different manufacturers, it is desirable to convert from a W/pixel metric to W/sq ft by multiplying the energy use per pixel by the number of pixels contained within one square foot, according to the pixel pitch of the display. The following equations detail how pixel pitch is used to calculate W/sq ft, and then W/sign, from W/pixel:

$$Pixels\ per\ sq\ ft = \left(\frac{1}{pixel\ pitch} * \frac{304.8mm}{1ft} \right)^2$$

$$Watts\ per\ sq\ ft = Watts\ per\ pixel * pixels\ per\ sq\ ft$$

$$Watts\ per\ sign = sq\ ft\ per\ sign * Watts\ per\ sq\ ft$$

Second, it is necessary to ensure that assumptions around display image and brightness are consistent. For example, different colors (i.e. image content) require different amounts of power, with white being the most energy intensive. Displaying an image that is mostly dark colored might require only 30% of the total power needed for displaying a bright white sign. Furthermore, sign brightness can be highly variable, ranging from 100% of full brightness during the brightest periods of day, down to 3% of daytime brightness at night (Watchfire 2012). Energy use therefore will also vary roughly within that range. As such, it is necessary to normalize any reported energy use metric with brightness, as well as color, before attempting to compare W/sq ft between one product and another. This approach of accounting for brightness into a watts-per-area metric is also similar to how energy use is measured for other digital display products, such as televisions and computer monitors, which use watts per square inch after displaying a standardized video image test clip and having the luminance recorded.

5.2 PER UNIT ENERGY USE

As previously stated, the energy use information provided by manufacturers often lacked specificity around display image content and display brightness. Assuming that all data listed in Table 1 reflect 100% full output displays at maximum brightness (i.e. displaying an image that is 100% white in color), and that the maximum brightness of all displays is equivalent, our research identified a range of **16** to **51 W/sq ft** for a current generation DBB. In order to calculate the annual energy use of a DBB, additional assumptions around typical duty cycles and operating modes are needed. For this report, we assume that a DBB will be operating for 24 hours a day (12 hours daylight, 12 hours nighttime), that the display will operate at full brightness (which is capped at 50% of achievable

maximum brightness, due to sign color and content) during the day, and that nighttime operating power will be significantly lower than daytime operating power as reported by manufacturers. Ultimately, ambient light levels as well as customer choice play a major role in how much sign brightness is dimmed at night. For calculations in this report, a value of 40% was used. Table 2 describes the basic assumptions required for calculating the energy use of DBBs.

TABLE 2. BASIC ASSUMPTIONS FOR CALCULATING THE ENERGY USE OF DBBS

Parameter	Assumed Value
Daylight hours	12 hours
Nighttime hours	12 hours
Daylight operating brightness	100%
Nighttime operating brightness	40%
Average color of message content¹	50%

¹ As noted in Section 5.1, designs that contain heavy whites, or light colors, use more energy than those using darker colors or primarily black

The following equation describes how the assumptions presented in Table 2 are used to calculate annual energy use for a typical 14 feet by 48 feet (598 square feet) sign:

$$AEU = \frac{W}{ft^2} * \frac{598ft^2}{sign} * 50\% * \left(\frac{12hrs}{1day} * \frac{365days}{1yr} * 100\% + \frac{12hrs}{1day} * \frac{365days}{1yr} * 40\% \right) * \frac{1kW}{1000W}$$

Using these assumptions, DBBs may consume between **29,000** and **94,000 kWh per year**. More manufacturer data on actual LED efficacy by color and brightness level is needed to be able to more effectively estimate the expected energy consumption of these products when installed in the field. These calculations are summarized in Table 3.

TABLE 3. SUMMARY OF RANGE OF REPORTED DBB ENERGY USAGE METRICS, CONVERTED TO ANNUAL ENERGY USE

Reported Energy Use by Metric	Energy Use per Square Foot (W)	Energy Use for 14'x48' Sign (W)	Annual Energy Use (kWh)
0.14 – 0.2 W/pixel	46 – 51	20,000 – 30,000	85,000 – 94,000
16 – 20 W/ft²	16 – 20	10,000 – 12,000	29,000 – 37,000
15,000 W/sign	25	15,000	46,000

It should be noted that the energy use estimates presented in this section do not include the energy use of other DBB components beyond the display, such as the computer and the cooling system, because these components contribute a relatively small fraction of total DBB energy use.

5.3 STATEWIDE ENERGY USE

As described in Section 4 (Installed Stock), we estimate the total number of DBBs in California to be around 250 to 300. This corresponds to a range in statewide annual energy use of between **7** and **28 gigawatt-hours** (GWh), based on the variability in product energy use uncovered through manufacturer outreach efforts and the uncertain range in existing stock. However, many of the billboards operating in the field today were installed several years ago, using less efficient LEDs. Basing statewide energy use on the range of product energy use presented in previous studies (Young 2010), annual energy use in California could be as high as **90 GWh**.

As the stock of DBBs continues to grow, statewide energy use of this product type is likely to increase significantly. Assuming that 50% of all static billboards in California are eventually converted to DBBs, statewide energy use for these products could reach up to **1.6 terawatt-hours per year**, based on the product performance range identified in this study. Table 4 presents a summary of statewide energy use estimates generated in this study.

TABLE 4. STATEWIDE ENERGY USE ESTIMATES

Scenario	AEU per Sign (kWh)	Current Stock in California	Potential Stock in California	Current Statewide Energy Use (GWh/yr)	Potential Statewide Energy Use (GWh/yr)
High Performance DBBs	29,000	300	17,000	7	493
Low Performance DBBs	94,000	300	17,000	28	1,568

5.4 SAVINGS POTENTIAL

The manufacturers that contributed to this study stressed the importance of energy efficiency as a key selling point to customers, as electric utility bills for individual signs can be hundreds of dollars per month. Though manufacturers claim that the energy efficiency of their DBB products has improved steadily over the past several years due largely to advances in LED and power supply technology, there are still significant differences in the amount of energy used among products from different manufacturers.

Many manufacturers cited LED quality as a key indicator of energy performance. One manufacturer provided an example of two DBBs from different vendors with dramatically different energy requirements. One efficient billboard used less than one third of the energy of the less efficient product. Through this example, the manufacturer suggests that the savings potential from using high

quality LEDs over low quality LEDs can be upwards of 70%. This likely represents the upper bound of potential energy savings that can be achieved through the use of higher quality LEDs.

In addition to differences in light source efficiency, manufacturers also mentioned the importance of automatic brightness controls in ensuring that DBBs are not using more energy by over-lighting images during times when the image does not need to be as bright (i.e. at night). These controls typically involve the use of a photocell to detect ambient light levels, which determines how much power should be supplied to the LEDs. The accuracy and quality of the photocell can significantly affect the energy use of a given sign. One manufacturer advertises a 23% reduction in energy consumption through the use of a multidirectional light sensor that is better able to measure ambient lighting conditions (Daktronics). Additionally, energy use depends heavily on how bright the sign owner wants the DBB to be and how the automatic brightness controls parameters for the sign are set. The energy savings potential from adjusting brightness control settings is highly variable depending on what the sign owner desires but can be significant if deeper dimming is acceptable by the sign owner. We estimate that approximately 20% to 40% additional energy savings could be gained by tuning the brightness controls to operate the sign at more conservative brightness levels.

Aside from improving LED quality and implementing improved brightness controls, other opportunities for reducing DBB energy use also exist. For example, power supply efficiency varies from manufacturer to manufacturer. Though the range in quality between the best and worst products is less dramatic than with LEDs, using a more efficient power supply may produce some energy savings over lower efficiency or older generation power supplies. Since the energy use of power supplies is a relatively small contribution to the total energy use of a DBB, energy savings for increasing the efficiency of power supplies is likely limited.

Additionally, some DBB manufacturers take different approaches to managing heat generated by the display. While a cooling fan is typically needed to prevent the computer, LEDs, and power supplies from overheating, some DBBs are able to smartly control the fans to only operate when temperatures reach levels that require active cooling. Other DBB manufacturers are exploring passive cooling techniques, such as liquid insulation that also reduces active cooling energy needs. In terms of overall energy use, however, active cooling is a relatively minor component, and improving the efficiency of the cooling system will only result in an average total power reduction of a couple hundred watts at most.

In our discussions, manufacturers did not identify the impact of display resolution or pixel configuration on DBB power needs as a major energy efficiency issue. As previously mentioned, higher resolution displays contain more pixels and/or pixel configurations which contain more LEDs per pixel result in a greater number of total LEDs; with a greater number of LEDs, the maximum achievable sign brightness is also increased. A higher LED count therefore allows the DBB to operate individual LEDs at lower drive currents in order to achieve the same sign brightness of a DBB with fewer LEDs. Operating at lower drive currents generally helps extend LED lifetime by reducing heat to the LEDs. Depending on how the LED and power supply have been designed, lowering the drive current may also slightly increase LED efficacy, and therefore, operating efficiency. Additional research is needed for understanding how display resolution or pixel configuration may affect power needs for DBBs.

In summary, the key energy savings opportunities for DBBs come from the use of high quality LEDs and tighter brightness control settings. Together, by focusing only on these two energy saving measures, we estimate that power reductions up to 85% are possible, between the most and least

efficient products. This translates to potential annual energy savings of around **80 MWh per sign**, or up to **23.8 GWh per year for the total installed base** of DBBs in California.

5.5 TEST PROCEDURE CONSIDERATIONS

In order to accurately characterize the energy use of various DBBs for the purpose of comparing the energy efficiency of these products, a standardized test procedure to measure the power consumption is necessary. Because DBBs are used to display a wide variety of images, each with different color schemes and brightness levels, the test procedure must account for variations in the energy intensities of displaying different colors. One possible approach could be to measure the total energy use of a DBB with a standardized dynamic video clip, similar to what is used in the test procedure to measure the energy use of televisions for compliance to the California's Appliance Efficiency Standards (Title 20). The standardized dynamic video clip would represent display content that would reasonably approximate content on DBBs. Additionally, since DBBs typically use automatic brightness dimmers that operate differently, the test procedure should also include energy measurements at different brightness (i.e. luminance) levels typical of different operating conditions, similar to how televisions with automatic brightness control features are tested.

Given the large size of this equipment type, it will be challenging to measure sign brightness without interference from ambient light sources. As such, another possible approach to measuring DBB energy use and brightness is to focus on the individual components of each sign. In such a test procedure, a single LED pixel, or a small group of LED pixels of predefined size, would be evaluated for energy use and brightness. Energy use of additional DBB components, such as the computer and fans used for active cooling, would be metered separately. This "bottom-up" approach is preferable, at least in the short term, as it provides significant additional detail on component-level energy usage. This type of data can then be used to identify key differences between products from different manufacturers and help isolate opportunities for performance improvements for all DBBs.

Significant additional research is required to develop the appropriate test procedure parameters. As a first step, metering data should be collected for field installed DBBs and for individual DBB components. Also, it may be necessary to survey sign manufacturers and owners to learn more about common display colors and patterns, as well as default brightness control settings, in order to better understand typical operating profiles.

6 UTILITY INCENTIVE PROGRAM CONSIDERATIONS

As DBBs are becoming increasingly more popular and more DBBs are installed around the state, the savings potential from incentivizing the installation of more efficient DBBs is significant. A utility incentive program could be especially effective for this product, given the relatively small number of relevant market actors. With a reasonable amount of outreach and marketing, a utility program could easily insert itself into the distribution chain and begin influencing customer purchase decisions.

This report identified brightness controls and the quality of LEDs and power supplies as the primary strategies for ensuring efficient operation. A utility incentive could be based on the following prescriptive measures:

- Minimum LED efficacy (lumens per watt)
- Minimum power supply efficiency
- Mandatory settings for automatic brightness controls to limit display brightness below a certain threshold

Based on the analysis presented in the Energy Usage section of this report, the combined measures could yield a difference of 85%, between the best and worst performing products on the market. Some DBB topics that would need to be better characterized for the development of an incentive program work paper include:

- Improved understanding of the load profile of DBBs.
- Research on the incremental cost of the efficiency improvements outlined in this report.
- Understanding of the vintage of installed DBBs.
- Annual shipments analysis and projections.

7 CONCLUSIONS & FUTURE RESEARCH

Given the large power requirements and constant usage, DBBs consume a significant amount of energy. However, there are a number of opportunities to continue increasing the energy efficiency of DBBs, particularly as more advances are made in LED and power supply technologies. An incentive program could help influence 1) manufactures to design more energy efficient products or 2) influence purchasers to buy and install only the most efficient equipment. Given the potential for technologically feasible energy savings, a utility rebate program that incentivizes the purchase and installation of more energy efficient DBBs could result in significant energy savings and corresponding greenhouse gas emission reductions for California.

7.1 FUTURE RESEARCH OPPORTUNITIES

Based on the information collected from manufacturers, sign owners, existing studies, and web-based resources, it is evident there is a lack of consistent data and documented information pertaining to the energy use of DBBs. In order to accurately characterize the energy use of this ubiquitous equipment, additional research opportunities are presented below.

7.1.1 Field Monitoring

By metering DBBs currently installed in the field, it will be possible to corroborate manufacturer claims pertaining to product energy use and efficiency. Ideally, it would be best to study DBBs of the same size from multiple manufacturers installed in different years to identify differences in energy consumption. Furthermore, it will be necessary to work directly with the owners of the signs being metered to gain an understanding of sign content and brightness settings. Field monitoring may also reveal differences in energy use among products installed in different climate zones. Finally, field monitoring over the course of several days can help better understand usage cycles and, potentially, contributions to electricity load during peak times.

7.1.2 Teardown Analysis

By breaking a DBB into its component pieces and studying the display, cooling system, computer, and brightness controls separately, it may be possible to more accurately assess the most effective opportunities for improving energy efficiency. A thorough teardown analysis would require close collaboration with manufacturers to obtain access to pre-assembled components for hands on testing.

7.1.3 Utility Data Analysis

Collecting and analyzing utility data on DBB energy use will provide important insight on high level DBB energy use patterns. Customer permission is typically required before utilities are able

to release billing information, so it will be necessary to work closely with utility representatives and sign owners to obtain the data. The level of specificity in the data will dictate the efficacy of the analysis in revealing trends in DBB energy use and efficiency.

7.1.4 Cost Analysis

Additional research on the cost of improving energy efficiency is needed before incentive programs or policy changes can be recommended. This would involve researching the cost to the sign manufacturer of using improved DBB components, such as higher quality LEDs and power supplies, and developing an understanding of how these costs are passed onto the sign owner and/or the advertiser.

7.1.5 On-premise Signs

Billboards are classified as “off-premise” signs typically large in size and located along highways and busy surface streets. Conversely, “on-premise” or “accessory” signs are those installed on a business’s property. Though there are significantly more on-premise digital signs in existence than DBBs, there is more variability in sizes and applications when looking at on-premise digital signs. Since the technology behind DBBs and on-premise digital signs are similar, many of the technological issues presented in this report can be applied to on-premise signs as well. Further research is necessary to accurately characterize the market and energy savings potential of these types of signs following similar methodology we used to characterize DBBs in this report.

7.1.6 Determining Demand Response Potential

DBBs can contribute to peak loading since they typically at maximum brightness levels, corresponding to maximum power draw, to compete with ambient lighting conditions that are brightest during daily system peak demand for electricity. Additionally, during peak hours when it is warmest, a DBB cooling system will likely need to run more frequently. Further research is required to better understand the potential to reduce the electricity demand of a DBB, and its components, during peak hours and still adequately meet advertisers’ needs.

7.1.7 Best Practice Guide

Due to the lack of uniformity in referencing the energy use of DBBs, a best practice guide would be useful to educate sign owners and advertisers on common DBB energy use metrics and efficiency considerations. Additionally the guide could provide detail on very specific energy efficient practices they should consider when operating and advertising on DBBs. Development of the guide would involve the solicitation of input from all stakeholders, including manufacturers, sign owners, and advertisers to account for potential benefits, costs, and other considerations related to improving DBB energy efficiency.

7.1.8 Test Procedure Development

An industry standard test procedure is needed to ensure that accurate energy use is reported by manufacturers. Until a test procedure is developed, purchasers have no simple method for objectively comparing the energy efficiency of different products. Several ideas for test procedure considerations have been presented in this report, but significant additional research to collect actual energy use data and an enhanced understanding of certain technical issues, such as testing conditions, is needed. Many of the research avenues identified above may ultimately contribute to development of a test procedure.

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APPENDIX A: QUESTIONS FOR DIGITAL BILLBOARD MANUFACTURERS

1. Can you describe the full distribution chain for digital billboards, from component manufacturing to customer delivery/installation?
 - a. Where are your digital billboards manufactured (factory locations)?
 - b. How are the digital billboards shipped? Are the digital billboards shipped pre-assembled or in pieces?
 - c. Who installs the digital billboards (you or customer)?
2. Who do you purchase your LEDs from (e.g. manufacturer direct)?
 - a. What “tier” of LED manufacturer?
3. What are the most common sizes of digital bulletins and posters that you offer (e.g. 14x48, 12x24, 10x36)?
 - a. Is a 12x24 LED sign also marketed as a (highway) billboard/to billboard sign owners?
 - b. What is your bestseller(s) (i.e. most popular size)?
 - c. Do you offer custom projects (e.g. non-standard sizes/shapes/applications such as stadium scoreboards, etc.)? If so, what percentage of your sales are custom projects?
4. How many LEDs are typically in a 14 x 48 foot sign? 12 x 24 foot sign?
5. What are the industry standard resolutions for digital billboards and posters? What is the average pixel density (# pixels per square foot) for each?
6. What is the average lifespan of a digital billboard? What important assumptions are used in your lifetime estimate?
7. Do your digital billboards have auto-dimming and full brightness control capabilities (or any other advanced controls options)? How are these controls features implemented?
8. How is sign content managed? Remotely or on-site (i.e. are your digital billboards networked or do they have an onsite/built-in computer for content management)?
9. How many watts per square foot for the bulletin and poster signs?
10. Has the energy efficiency of your digital billboards improved over time? If so, how has it improved and by how much?
11. Do you receive questions about energy consumption or efficiency from your customers? Do you think the energy use of digital billboards has been a consideration for your customers when making they make purchasing decisions?
12. Is there an industry-accepted test procedure to measure the typical power consumption of digital billboards? If no industry-accepted test procedure, how do you conduct energy testing for your products?
 - a. Do you have any ideas on how a test procedure might be put together?
13. How much do your digital billboards cost on average?
 - a. Are digital billboards and static BBs cost competitive?
14. How much of an increase in digital billboard sales have you seen over the past 5 years?
 - a. Would you say the trend in digital outdoor advertising, particular billboard displays, is increasing slowly, moderately fast, rapidly?
 - b. What percentage of digital billboards and static billboards do you sell?
 - c. Approximately how many digital billboards have you sold in California?

- d. Are municipal ordinances or other regulations on digital billboards (in CA) impacting your sales in California?
15. Who are your largest California customers?
- a. How do you find new customers?

APPENDIX B: QUESTIONS FOR SIGN OWNERS

1. What territory(s) does your company operate in?
2. Does your company own digital billboards?
 - a. Are you increasing your stock to include digital billboards in new locations or replacing static billboards with digital billboards?
 - i. What is the incentive for changing outdoor signage from static to digital (if there is one)?
 - ii. Who is marketing/promoting the use of digital billboards (e.g. sign manufacturers; trade associations; advertisers)?
 - b. What percentage of your stock is comprised of digital billboards?
 - i. How many are bulletins (and what sizes) and how many are posters (sizes)?
 - ii. What is the most popular size?
 - iii. How many digital billboards do you have in California?
 1. What sizes?
 - c. How many digital billboards do you plan to install in the coming years?
 - d. Are you facing any regulatory barriers to installing digital billboards?
 - e. Can you describe the factors that influence the purchasing decision of a billboard product (e.g. cost, increased revenue/profit potential, brand; display performance/resolution, existing relationships with manufacturers, energy efficiency, customer interest in digital advertising)?
 - f. Approximately what percentage of your sign stock are digital billboards, static billboards, and “on-premise” LED signs?
2. Has there been a growing interest in digital billboard advertising among your customers?
 - a. What percent of your customers opt for digital billboard advertising versus static BBs?
 - i. Why do they choose one over the other?
 - b. Which medium do you prefer and why?
3. Can you describe the process for purchasing and installing a digital billboard? How are the digital billboards installed at the site (i.e. installation method)
 - a. Do you purchase digital billboard directly from the manufacturer?
 - b. Do you need to assemble the billboard or does it come pre-assembled?
 - c. What is your average cost for equipment and installation?
 - d. Have you seen a return on investment?
4. Can you describe the maintenance of digital billboards?
 - a. How often must the digital billboards be serviced?
 - b. What is the typical annual cost of operating a digital billboard?
 - c. What is the average monthly or annual cost of powering one sign?
 - d. What are the components of cost (e.g. maintenance, electricity)?
5. Are your digital billboards individually metered? If so, are you able to share this data (either confidentially or publicly)?
 - a. Do energy costs factor into your decision-making process?
6. Is the sign content managed onsite or remotely (e.g. networked)?
7. Does it cost more to advertise on digital than static billboards?
8. How do you bill customers?

- a. How does the billing structure or rates for digital billboards differ or relate to the billing structure for static billboards?
9. Does your company have digital billboards installed on city-owned properties?