# Reviving the War of Currents: Opportunities to Save Energy with DC Distribution in Commercial Buildings

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**ABSTRACT**

Distributed-generation resources and many of the electrical loads in today's buildings fundamentally produce and consume direct current (DC). The solution for decades has been for each device to convert alternating current (AC) into low-voltage DC through power supplies, lighting ballasts, and motor drives. Our estimates show that today's commercial office buildings lose about 13% of their electricity every year simply distributing and converting power from the utility meter down to the point where it can power equipment. The loss is even higher for high-performance designs, like zero net energy (ZNE), which possess additional power-conversion stages for on-site generation, such as photovoltaics (PV).

We examine an alternative approach: DC distribution "islands" within commercial buildings that eliminate the need for repetitive power-conversion steps. We summarize the state of the industry-led effort for DC distribution, including current technology, demonstration projects, cost-effectiveness, and ancillary benefits. Significant market barriers to implementation exist, for example, the trades have little to no experience with DC, and there are few DC-powered products available today. With these barriers, tapping into the energy savings will not be easy. However, the best opportunity exists in ZNE commercial office buildings where designers can leverage synergies between DC loads and PV power generation. In ZNE commercial office buildings, we estimate that the elimination of redundant conversion steps and smaller, less-efficient power-conversion devices could shave building electric consumption by as much as 8%.

## Introduction

Commercial buildings currently consume more than 30% of all electricity used in the United States and electric consumption in this sector continues to grow despite recent national declines in electric sales (EIA 2013). Architects and engineers are increasingly working to reverse this trend by focusing on high-performance building designs and targeting ZNE in new construction and retrofits. The number of North American commercial ZNE buildings, which annually use no more energy than they produce from on-site renewable sources, has more than doubled in the last two years, to a total of 160 (NBI 2014).

As high-performance building designs, like ZNE, optimize the energy performance of HVAC, lighting, and building-envelopes, the electric consumption of those buildings is increasingly dominated by miscellaneous end uses, including plug loads. These miscellaneous loads have proven difficult for architects and engineers to address systematically because their efficiency is not usually governed by building codes or appliance standards, and which equipment is selected and how that equipment is used is not usually within the purview of the building designer. The tools that enable facility engineering managers to address miscellaneous loads have not kept up with the rapid pace of innovation of new plug loads and office equipment. Most of these loads—computers, consumer electronics, and other office equipment—inherently run on direct current (DC) electricity, so they must convert the AC electricity provided by the grid. Each conversion yields a loss, and we estimate[1] that these losses, including energy losses in the building wiring and in the devices themselves, account for 13% of a code-built commercial office building's energy use (Figure 1) in California.

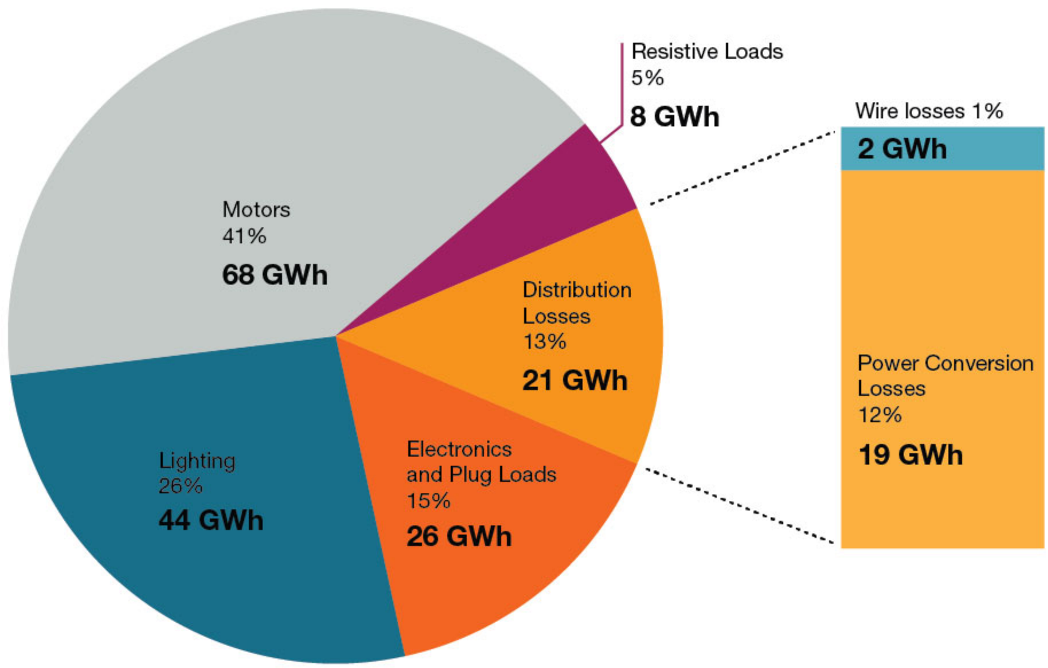


Figure 1. Loads and losses in California commercial office buildings (Ecova 2012).

The underlying premise of considering DC distribution[2] as an energy efficiency strategy is the opportunity to reduce energy losses by consolidating or eliminating power conversion steps. In ZNE buildings, conversion losses are even more significant than standard commercial office buildings. They are particularly dense with high-tech low-energy technologies, such as adjustable speed drives for motors and LED drivers, both of which operate on DC. These types of ZNE buildings in particular are especially promising candidates for such DC power systems because office buildings have a relatively high density of electronics compared to other commercial buildings and their loads generally coincide with daytime hours when PV panels supply electricity. With standard AC distribution in a ZNE building, as current flows from the PV to the DC load, it may pass through as many as three conversion stages before it can be

[1] A description of the model used to produce this statewide estimate is in the section titled, "Benefits and Energy Savings Estimates in Commercial Office Buildings." We calculated the power conversion losses in a small office building that is representative of CA code-compliant small office buildings today, and then scaled up that estimate to create an estimate of magnitude of the statewide impact of these losses in all commercial office buildings.

[2] The literature may refer to these as "micro-" or "nanogrids."

applied to low voltage (LV) lighting, motor, and electronic end uses. With DC distribution, coincident DC loads can use PV-generated power without the need for redundant inversion and rectification steps (a couple of high efficiency DC to DC conversions are typically required to achieve LV required at the end use). Figure 2 illustrates some typical power flow paths for electricity in today's AC distribution buildings and the envisioned DC distribution approach.

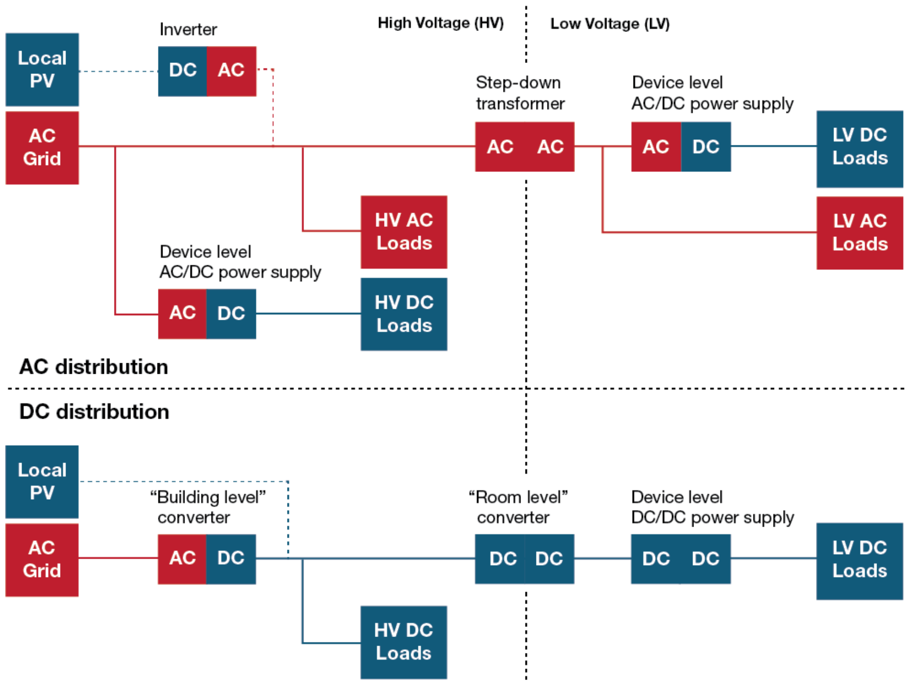


Figure 2. Schematic of AC and DC distribution approaches[3].
*HV and LV mean high voltage and low voltage, respectively

Whereas DC distribution systems in data centers and residential buildings have been analyzed (Ton, Fortenberry, and Tschudi 2008; EPRI 2011, Aldridge et al. 2007, and Baek et al. 2011), there has been little work conducted on commercial office building opportunities (Frank 2013). To begin to fill this gap, Pacific Gas and Electric Company (PG&E) engaged Ecova to examine savings opportunities associated with DC distribution systems in such buildings. This research was in the context of the California Public Utilities Commission ambitious — albeit non-binding —target to achieve ZNE in all newly constructed commercial buildings by 2030. Further details and full findings are available in that final report (Ecova 2012). In this paper, we first provide an overview of the current state of DC distribution, including a summary of benefits and barriers, then we discuss the model we created to evaluate the energy savings potential associated with DC distribution in both code-compliant and ZNE commercial office buildings. Finally, we present the results of our cost-effectiveness modeling and identify the most promising end-uses for DC distribution.

[3] For the purposes of our investigation, we assumed that a building with DC distribution would only have DC loads, which generally are the highest efficiency technologies that would likely be selected for a ZNE building.

## The State of Local DC Distribution Systems

With a growing number of native DC loads and generation sources in commercial buildings, interest in DC power systems continues to build. But for these systems to achieve broader adoption, standards are required to enable consistent DC voltages. The voltage requirements of native DC equipment differ vastly from the standard voltages at which grids typically provide AC power. For example, plug load devices can require anywhere from 5 $V_{DC}$ for USB products to 48 $V_{DC}$ for certain telecommunications equipment (Figure 3). No one voltage dominates. This creates a challenge for anyone designing a DC distribution system, because one must eventually standardize one or two voltages to supply the building's equipment.

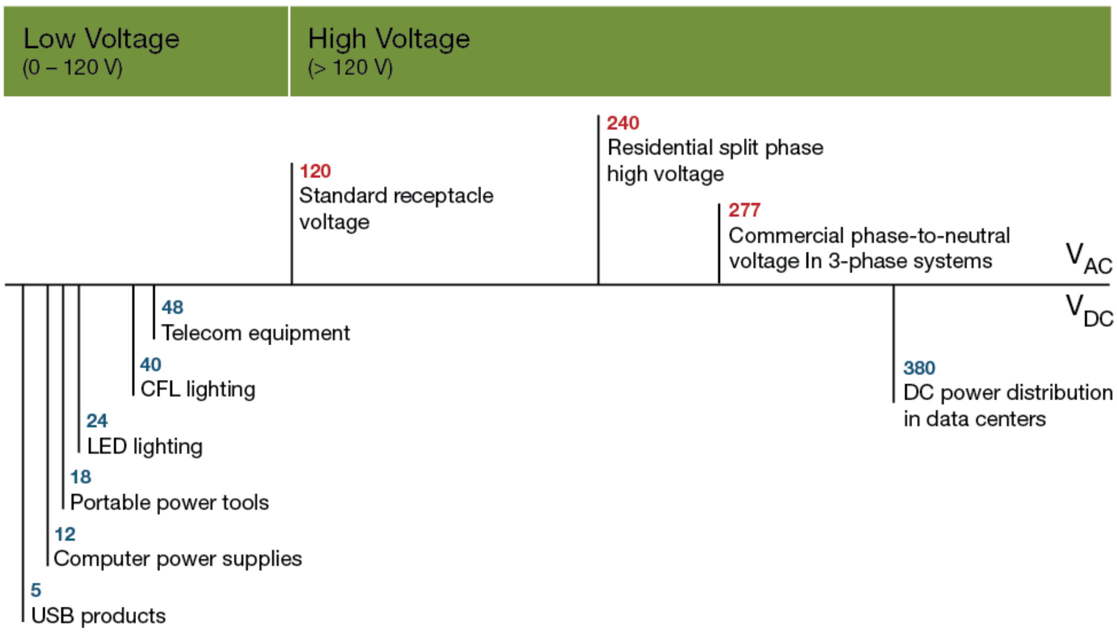


Figure 3. Common AC and DC voltages in high- and low-voltage products.

Industry-led efforts are beginning to tackle this difficult issue to ease the transition to building-level DC distribution. Of particular interest for commercial office buildings is the EMerge Alliance's Occupied Space Standard, an open standard available since 2009 for power, interior infrastructures, controls, and peripheral devices to facilitate the hybrid use of AC and DC power within commercial buildings. Under EMerge's proposed system architecture, conversion of AC power occurs in one central power supply in each room. Low-voltage DC then flows via conductors in the suspended ceiling grid to power lights and other DC loads. If PV is available, its DC output can be connected directly to the power supply, eliminating the need for an inverter and avoiding unnecessary power-conversion steps. There are more than 60 products for lighting systems registered with the EMerge Alliance today, from manufacturers such as Philips, Osram Sylvania, and Armstrong.

EMerge Alliance's next step toward the goal of a singular DC distribution system is to address plug load equipment such as task lighting, computers, monitors, and cell phone chargers in order to allow users to power these devices with DC power at their desks. This will be done by integrating DC power into walls, furniture, and floors, in addition to the suspended ceilings currently included in the standard today. Adding plug load equipment would enable DC distribution for the majority of office equipment and lighting, and will be a significant step toward cost-effectively realizing possible savings from DC distribution systems.[4]

Table 1. DC distribution standards

| Standard | Application(s) | Organization(s) | Voltage | Notes |
|---|---|---|---|---|
| EMerge Alliance Data/Telecom Standard | Distribution in data centers and telecom central offices | EMerge Alliance and EPRI task force | 380 $V_{DC}$ | Completed in 2012 |
| ETSI EN 300 132-3-1 - V2.1.1 Standard | Telecom distribution | European Telecommunications Standards Institute | 400 $V_{DC}$ | Completed in 2012 |
| IEC SG4 | Distribution in areas where LVDC is used | International Electrotechnical Commission (IEC) | 400 $V_{DC}$ - 1500 $V_{DC}$ | Set up in 2009 |
| USB Power Delivery | Consumer electronics and office equipment up to 100 W | USB Alliance | 5 $V_{DC}$ | Completed in 2014 |
| Residential DC Power Initiative | Residential and small commercial | EMerge Alliance | | Initiated in 2013 |
| EMerge Occupied Space Standard | Commercial interior infrastructures | EMerge Alliance and EPRI task force | 24 $V_{DC}$ | Completed in 2013 |
| IEEE 802.3 | Power over Ethernet for networked devices | IEEE | Various | Completed in 2003, revised in 2005 and 2009 |

Another promising development from the world of plug loads is the USB Power Delivery specification, which could harmonize the way plug loads receive DC power. The specification delivers 5 $V_{DC}$ to devices via a USB cable, allowing power of up to 100 W.[5] This specification may provide a standardized means to power common office products and consumer electronics—many of which already support USB.

Even though some of these standards are nascent, early adopters have begun to experiment with DC distribution and a number of DC demonstration projects have been completed at more than a dozen locations, mostly in the U.S. (EPRI 2006, Marney et al. 2012). Lighting-based projects used the EMerge 24 $V_{DC}$ standard, and the approach for non-lighting end-uses varied. Some notable examples include:

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[4] As it works toward its singular DC distribution system goal, EMerge Alliance envisions a transitional period during which buildings would maintain a hybrid power distribution system. DC would power the most appropriate end-uses, while AC would continue to power equipment that does not yet support a DC bus.

[5] For more information on the USB Power Delivery Specification, see http://www.usb.org/developers/powerdelivery/

- A warehouse in Rochester, New York, where PV power generated onsite was distributed as DC to office and warehouse lights, improving efficiency by up to 20% (EPRI, 2006).
- Integral Group, a green architectural engineering firm known for its design of ZNE buildings, installed an Armstong FlexZone ceiling lighting system in its Oakland, California, office for demonstration purposes.
- The PNC Financial headquarters in Pittsburgh, Pennsylvania, installed a DC ceiling and deployed similar systems in a number of branch banks.
- Japanese microgrid demonstration projects in Sendai and at the Aichi Institute of Technology (AIT) in Toyota City (Marney et al 2012).

## Market Benefits and Barriers to DC Distribution

Non-energy benefits of DC distribution may serve as a key driver for system installations occurring to date. Benefits include:

- **Reduction in electronic waste.** Nearly any consumer electronic product purchased today is sold with an AC-DC power supply, but this power supply could be eliminated and its function replaced by building level AC-DC converters that provide DC power to an entire floor or building. These larger building level converters would be replaced less frequently than most consumer and office electronics, thus reducing electronic waste.
- **Easily reconfigurable overhead lighting**. Our review of existing DC ceiling grid systems in commercial office spaces shows that one of the primary benefits is the ease and flexibility with which overhead lighting can be reconfigured. This is a task that normally requires an electrician, but when DC power is provided to overhead luminaries at low voltages (i.e. as Class 2 wiring), lighting systems can be reconfigured by one maintenance staffer with a ladder.
- **Improved power quality.** DC distribution systems have the potential to improve a facility's overall power quality, particularly if large numbers of plug loads can be run off of building-level AC-DC converters. Most larger power conversion devices in buildings today (e.g. motor drives, server power supplies, etc.) are required to have power factor correction (PFC) to ensure that they draw current in a smooth sinusoidal pattern rather than in abrupt spikes. The power supplies used in smaller electronic devices—cell phones, laptops, and monitors—often lack PFC circuitry and tax the grid more heavily by requiring intense pulses of current. If those smaller plug loads ran off of larger building-level AC-DC converters with PFC, it would generally improve the power quality on the grid. An overall improvement in power factor can have some small, ancillary energy efficiency benefits as well.

In addition to non-energy benefits, there are also significant barriers:

- **Legacy AC distribution.** As long as the larger generation, transmission, and distribution grid is based on AC, fundamental barriers to DC electric distribution will remain in grid-tied buildings. Trades are not familiar with the different wiring standards, and building occupants are familiar with using AC plugs.

- **Lack of DC-ready products and high costs.** Currently, lighting products (utilizing the EMerge Occupied Space Standard) and small electronics (utilizing the USB Power Delivery or Power over Ethernet standards) are the DC-input end uses available for a commercial office building today. Currently, AC-DC and DC-DC room-level convertors are sold in fairly small quantities. These convertor boxes, other components that support the DC distribution infrastructure and many end-use products have not yet achieved economies of scale that we see with more mature technologies. Furthermore, original equipment manufacturers (OEMs) of larger office electronics (e.g. printers and desktop computers) and motor-driven end-uses (e.g. HVAC units) do not have models that support DC input. Standardization and engagement with OEMs could help initiate the design of more DC products.
- **Safety.** High-voltage DC is much more prone to arc flash than high-voltage AC. The current EMerge Occupied Space Standard mitigates this risk by using 24 $V_{DC}$ for receptacles.
- **DC wiring losses.** Dropping the voltage of an existing 120 $V_{AC}$ design to 24 $V_{DC}$, while providing the same amount of power and maintaining the same circuit length, increases wiring costs by an order of magnitude due to the larger conductors required to limit wire losses. To mitigate this cost increase, shortening the branch circuits might be possible in some, but not all, buildings.
- **System level outages**. System-level outages may be more common in DC infrastructure than in AC. Instead of a power supply on each device, DC buildings use large, room-level AC-DC or DC-DC convertors. Thus, the failure of one convertor would affect the entire downstream system in a DC building. This could be addressed with redundant building level convertors, careful engineering of convertor hardware to reduce probability of failure, or regular retirement schedules for convertors before end of life.

## Modeling DC Distribution in Commercial Office Buildings

To understand whether there are cost-effective energy savings opportunities for DC distribution in commercial office buildings, we developed a power flow model that estimates the wiring losses and power conversion losses for code-compliant and ZNE offices, evaluated energy savings opportunities, and ranked cost-effectiveness for end uses.

### Approach and Modeling Assumptions

To quantify the opportunity of building-level DC distribution, we constructed a detailed energy use and cost comparison model that accounted for the physical differences between AC and DC distribution systems and how they affect total building energy use and construction costs. We estimated energy savings associated with DC distribution for a 50,000 square foot office building under two scenarios: one code-compliant (represents current building stock built under California's Title 24 code) and the other ZNE. In both cases, we compared electricity conversion and consumption with an AC distribution system to one with a singular DC distribution system. We included in our model the cost and characteristics of the electricity sources, the building distribution wiring, the AC-DC, DC-DC and DC-AC conversions at the building and device levels, and the inherent efficiency of the end use loads. We used the following assumptions:

- **Electric rate, PV sizing pricing:**[6] We assumed a retail cost of electricity of \$0.16 per kWh. We developed an equivalent price of electricity to reflect the added cost of on-site PV and inverter: \$0.25 to \$0.30 per kWh.
- **AC distribution building wiring characteristics and cost**:[7] The AC case was based on a standard National Electric Code (NEC) wiring approach for a commercial building (277 $V_{AC}$ three-phase, and 120 $V_{AC}$ single-phase).
- **DC distribution building wiring characteristics and cost**:[7] Based on a survey of literature and examination of proposed industry standards, we assume that DC power will be distributed at two voltages in the building: 380 $V_{DC}$ and 24 $V_{DC}$. We also assumed shorter low voltage circuit length than typical AC distribution, and accounted for HV-LV convertor boxes around the building to enable that configuration.
- **End-use energy profiles efficiency**: We divided end uses into six categories: motor (HV and LV), lighting (HV and LV), resistive (LV) and electronics (LV). For code-compliant buildings, we used typical electric load assumptions from large California-based surveys and case studies (CEUS 2006). In the ZNE case, we adopted energy-use intensities as reported in prominent case studies (NREL 2012b). We assumed no change in efficiency of equipment as we moved from the AC distribution case to the DC distribution case.[8]
- **Power conversion efficiency in the building infrastructure and end-uses:** We used 96% efficiency for the DC-AC (inverter) (NREL 2012a). We assumed efficiency of the DC-DC convertor boxes used in the DC cases were 95%. We adopted AC-DC power conversion efficiencies that would be typical of the motor, lighting, resistive, and electronic loads found in the code-compliant and ZNE scenarios.
- **Cost assumptions for end-use equipment:** Although we were able to identify costs for existing AC equipment, DC-input equipment for many end-uses does not yet exist. We assumed for the DC case that all equipment was DC (no AC end uses). Given that DC appliances have fewer components, we assumed that capital costs of DC products were generally lower than AC products because we were considering a scenario where these products reached larger volumes typical of more mature technologies.

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[6] These figures were representative of California rates a few years ago when we completed the initial model. Although high relative to current California and national averages, the decrease in the electric rate does not impact the cost-effectiveness conclusions presented herein. \$0.16 per kWh is the bundled rate reported by the PUC for PG&Es service territory (CPUC, 2011). We used a National Renewable Energy Laboratory PV model (NREL 2012a) to establish PV sizing based on typical solar conditions in Sacramento, California. We priced PV installations, including labor, balance of system components, etc., at \$5 per W. We also assumed that ZNE buildings participate in net metering programs, with credit for PV production given at retail rates.

[7] To estimate wiring costs, we used June 2012 pricing for wire and cable in quantities purchased for commercial new construction. See Figure 2 for an illustration of the conceptual approach to wiring in the AC and DC scenarios.

[8] This is slightly different from the approach taken in the Ecova 2012 paper, where the share of DC motors differed in the AC and DC scenarios for the code-compliant scenario. For this report, we assume 100% DC motors in the AC and DC cases to ensure the energy saving presented only captures the savings associated with the change to DC distribution.

Our cost-effectiveness analyses used a 5% discount rate and 20-year DC system lifetime.

**Results: Energy Savings**

Our modeling revealed that a complete transition to DC distribution in a code-compliant building results in an increase in overall energy use (Figure 4). As expected, conversion losses at the device level are lower with DC distribution because AC-DC conversion takes place at the building level instead of the device level. This building level conversion is a significant source of energy loss in the code-compliant building because 100% of the energy used to supply the building comes from the AC grid and must be converted to DC to distribute in the building. Although under the DC distribution scenario, code-compliant building losses decrease with small electronics (< 100 W), these losses are offset with increases in losses for the lighting, motor, resistive, and larger (>100 W) electronics. Certain end-uses (such as all electronics and lighting) could be bundled together on a DC distribution system to reduce net losses in code-compliant office buildings, and that would require two distribution systems: one AC, to serve other end uses, and one DC. DC distribution could also be further investigated as a strategy for ZNE readiness in code-compliant buildings.

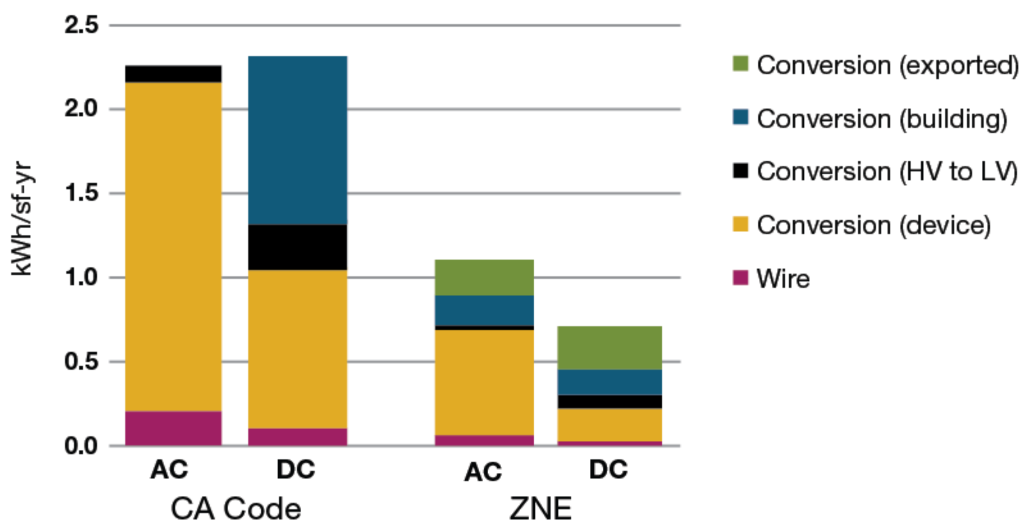


Figure 4. Estimated electric distribution and conversion losses in commercial office buildings.
*HV and LV mean high voltage and low voltage, respectively

Our results for ZNE buildings are much different. DC distribution saved about 8% of total ZNE building energy use. Because more of the loads can be powered using DC energy produced on-site with PV, power conversion losses in the system (including the building, the HV to LV conversion, and the conversion at the device) are significantly reduced. Figure 5 shows a simplified illustration of the flow of energy to electronic devices in a ZNE building with an AC distribution system. If the PV inverter is 95% efficient and the electronic power supply is 70% efficient, then one-third of the generated power is lost in the conversions assuming that the load is coincident. Thus, eliminating the DC-to-AC-back-to-DC conversion significantly reduces conversion losses.

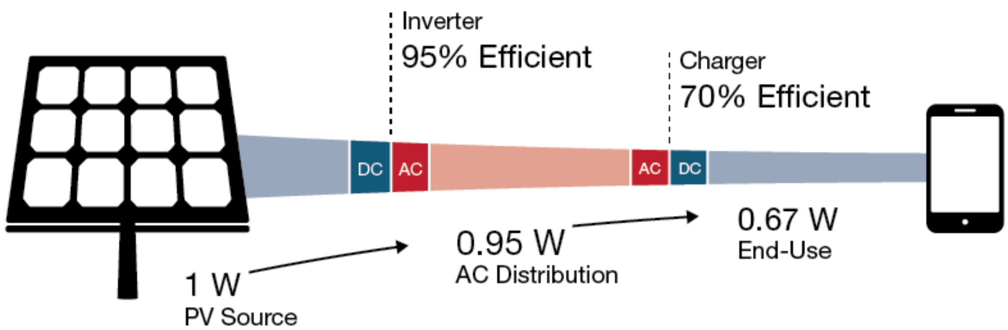


Figure 5. Conversion of 1 W from a PV panel (left) delivers 0.67 W of usable to an electronic end-use (right).

Lastly, in the case that DC distribution gains market traction, LED lighting systems and variable speed drives (VSDs) for large motor-driven systems (compressors, fans, pumps, etc.) are likely to be easier and cheaper to integrate into the buildings. Because the typical AC-DC conversion and power factor correction stages found in current LED lamps and VSDs would not be required, these already efficient end-uses could be the de facto technologies for DC distribution, saving additional energy not incorporated into our results shown in Figure 4.

## Results: Cost Effectiveness

We examined the cost-effectiveness of switching from an AC to a DC distribution system for each independent end-use (motor, lighting, resistive, and electronic) to identify the most promising opportunities for cost-effective savings.  The two elements that primarily drive the cost-effectiveness are 1) upfront capital costs, which generally go down with DC distribution when we consider a more mature market, and 2) energy savings, which result from reduction of AC-DC power conversion losses in the DC distribution scenario.

In the world of energy efficiency, we are accustomed to situations in which a technological advancement decreases energy use but also increases capital costs. Cost-effectiveness can then be easily measured in terms of dollars per lifetime kilowatt-hour saved. However, in this project, we saw several instances where switching to DC technology not only provided some energy savings but also may reduce the lifecycle capital costs of the system once the market matures. One example is electronic products, which could become cheaper if they no longer require the AC-DC front end of their power supply. Even though the first cost of highly mass-produced power supplies is quite low, they are replaced frequently; so the lifecycle capital cost of a more permanent building-level converter can be lower. These options effectively provide immediate payback, reducing both capital and operating expenses.

The code-compliant building scenario showed a net increase in losses with a move to DC distribution. In this scenario, electronic end uses are cost-effective, but resistive, motor and lighting end uses are not. Interestingly, lighting products are the only major end-use currently available among EMerge-registered products, yet our modeling shows that although building designers and tenants may prefer DC lighting products for other benefits, such as configurability, lighting is not a clear win from a cost standpoint in a code-compliant building.

Cost-effectiveness improves significantly in ZNE buildings not only because of the native DC electricity source (PV), but also because the typical AC system already contains a building-level power conversion stage—the PV inverter—so adding the required DC power-conversion infrastructure has less impact on incremental cost. With the exception of resistive end-uses, every end-use was independently cost-effective with the ZNE scenario, indicating that a singular DC distribution system makes economic sense for a ZNE building once the DC distribution market matures.

As with any forward-looking modeling exercise focused on emerging technology, we identified some values that, if changed, could affect the conclusions. For small electronics, we assumed that today's AC-powered products used power supplies with typical efficiencies. Best-in-class AC-DC power supply designs today are pushing efficiencies into the 90% range and could reduce some of the savings opportunity in this end-use category over time. Our study also identified the cost of building- or room-level power conversion gear as a key driver of overall DC system cost-effectiveness. These products are in the early phases of deployment and have not reached the economies of scale seen in inexpensive, commodity AC-DC power supplies. Our model assumes these economies of scale in our pricing approach. Lastly, as the cost of PV continues to decrease, efficiency opportunities like DC distribution that have significant barriers may be even harder to realize if more PV can be added to the installation. While more PV panels are not possible with high-rise, additional panels on a low-rise office complex may be feasible.

Lastly, standards have not yet been written to thoroughly enable DC-input motors and electronic loads, and DC-compatible products in these categories are elusive. DC motors are widely available in a range of voltages and capacities, but variable-speed drives that accept DC voltages as an input are not. Consumer electronics and office products were consistently one of the most cost-effective DC end-uses, but they too only exist in AC-input form.

## Recommendations

Although energy savings opportunities exist for DC distribution in both code-compliant and ZNE buildings, we focus our recommendations on ZNE, as these buildings provide the clearest cost-effective opportunity for energy savings. The most promising end-use applications today, along with their estimated energy savings and ancillary benefits are summarized in Table 2. All of these applications would provide immediate payback in a ZNE building using mature DC technologies because they would reduce the overall electrical system costs (Table 2). In order to develop the ranking of these opportunities, we considered load coincidence with PV production along with savings, cost-effectiveness, and consumer benefits.

Table 2. Near-term cost-effective applications of DC in commercial office ZNE buildings

| | End-Use | Best Available DC-Compatible Technology | 20-Year Energy Savings (kWh/sf) | Non-Energy Benefits |
|---|---|---|---|---|
| Good | Overhead Lighting | LED or fluorescent lighting coupled with DC drop ceiling | 0.7 | • Easily reconfigurable<br>• Easy to integrate controls (occupancy sensors, daylighting, etc.) |
| Better | HV Motors (HVAC) | DC motor coupled to VSD | 6.9 | • Simplified VSD design |
| Best | Electronics | DC-powered solutions do not exist, but variety of groups working toward standards | 2.5 | • Simplified power supply designs<br>• Reduced electronic waste<br>• Smaller devices<br>• Travel chargers not needed |

## Conclusions and Opportunities for Further Research

DC distribution is a promising energy-saving technology in certain applications. We estimated that DC distribution could reduce overall electricity consumption in ZNE commercial buildings by as much as 8%. This savings is likely cost-effective once DC distribution products reach market maturity. Cost-effective opportunities may exist with code-built commercial office buildings as a strategy for ZNE readiness. Alternatively, in a code-compliant building, DC distribution could be used with a bundle of end uses (such as lighting and electronics) that together produce cost effective energy savings, while other less cost effective end uses could continue to be powered with an AC distribution system. Many non-energy benefits, such as reduction in electronic waste, increased configurability for overhead lighting, and improvement of power quality, help to drive the growing industry support for DC distribution standardization. But there are also a number of significant barriers, such as legacy AC distribution, lack of DC-ready products, safety, DC wiring losses, and system level outages. These barriers need to be addressed to enable broader adoption of the technology.

Further research opportunities include 1) technology development of more DC-ready VSD-motor systems and large plug loads, such as computers and printers, and 2) independent third-party projects to acquire energy monitoring data that isolates the energy savings benefits of DC distribution installations.

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