PLANNING STORY

Revisiting the Campus Power Dilemma

A Case Study

by Mike Anthony, Patricia D. Koman, and Max Storto

The University of Michigan-led consortia of U.S. colleges and universities engaged in assertive advocacy in international infrastructure standards will support our industry's claim to excellence and contribute mightily to the innovation necessary for cities of the future.

FOREWORD

THE STEWARDS OF CAMPUS FACILITIES inherit a long conversation about striking the optimal solution among the competing requirements of safety, economy, and sustainability. In this article, we address the campus electrical power problem by bringing to light technical and financial considerations that we hope will contribute to national emissions-reductions ambitions. The University of Michigan-led consortia of U.S. colleges and universities engaged in assertive advocacy in the United States and the development of international infrastructure standards will support our industry's claim to excellence and contribute mightily to the innovation necessary in the future.

A NEW LOOK AT BACKUP POWER

Campus planners should make electrical engineers work a little harder before they approve another on-site generator. The familiar one-generator-per-building model for backup power needs to be revisited—not only in light of grim construction budgets and available space concerns but also because of fortuitous movement and new subtleties in the technical standards that govern backup power. A solution that nets an increase in overall backup power availability at a lower total cost of ownership and with less pollution is possible using approaches that more fully integrate district energy with independent perimeter utility sources, improved switching architectures, longer feeder runouts in regional backup power regimes, and loading generators.

The familiar one-generator-per-building model for backup power needs to be revisited.

For at least 50 years building codes and standards have had the practical effect of over-capitalizing life safety backup power at the expense of the business continuity power needed to recover from major regional disruptions such as the August 14, 2003, blackout in the United States or the more recent forced outages at the University of California, Berkeley. The case is proved by comparing frequency and duration data from the run-time of life safety generators at the end of their life cycle. Life safety generators dedicated to the purpose of assuring safe egress from a building are almost never used while power outages occur with significantly greater frequency and duration. There ought to be broader discussion in terms of reconciling the competing requirements of sustainability and safety in backup power systems with respect to life and property protection.

Understanding how these backup power systems protect life and property first requires dealing with the Babylonian confusion that surrounds the concept of backup power—in this article, a term of art that we use to describe *both* the mission of power systems engineered for life safety (or emergency power) and power systems engineered for the protection of property (or standby power). Owners are typically confused by the way architects (governed by the National Fire Protection Association (NFPA) suite of standards referenced in local building codes) differ from electrical engineers (governed by the Institute of Electrical and Electronics Engineers (IEEE) suite of standards) in their application of backup power concepts. Distinguishing between emergency and standby systems is essential because these systems require separate control and delivery paths. The word "mission" is used in order to expand the vocabulary surrounding backup power systems and to move the discussion of backup power into the quantitative realm (IEEE Std 493™-2007—Recommended Practice for the Design of Reliable Industrial & Commercial Power Systems).

DOING THE MATH

The University of Michigan has led the nation in driving quantitative methods of backup power system analysis into the NFPA suite so that sensitivity analyses can be applied to the complex and expensive array of choices that architects, engineers, and planners must make for campus power systems (Anthony et al. 2011). One- or two-variable decisions can usually be made using intuition, experience, and precedent. When three or more variables must be permuted and analyzed to make decisions about power security, assembling a mathematical model that permits engineers to prepare a set of choices for the campus planner will typically pay for itself. However, one of the reasons such a model is never assembled is that no one is quite sure how to pay for it because the core elements of the model involve more than one building.

The presence of a district energy (or campus cogeneration) system as the normal source of power sets up possibilities for safety and sustainability optimization that are often unknown or ignored because of the expense of keeping an engineering model up to date and useful. The parent standard for emergency and standby power systems for life safety within buildings—*NFPA 110: Standard for Emergency and Standby Power Systems*—permits the use of off-site utility sources of power for the life safety mission when the normal source of power is a district energy system classified by the Authority Having Jurisdiction as an on-site source (see sidebar 1).

SIDEBAR 1: EXCERPT FROM NFPA 110: STANDARD FOR EMERGENCY AND STANDBY POWER SYSTEMS

NFPA 110: 5.1.3 A public electric utility that has a demonstrated reliability shall be permitted to be used as the Emergency Power Source (EPS) where the primary source is by means of on-site energy conversion.

Commentary: When the normal source of power is provided by the electric utility, NFPA 110 does not recognize the use of another electric utility source as the backup source. However, when on-site energy conversion is used as the normal source of power—it is permitted to use a reliable electric utility as the backup source upon loss of the on-site primary system. This standard does not limit an on-site primary system solely to rotating equipment. Of course, other systems (fuel cells, photovoltaics, hydro, etc.) may be used for the normal source of power.

Source: NFPA 2013.

Most of the opportunities to use the utility as the backup lie on the perimeter, either as an overhead wire or an underground cable. Even when a perimeter source is not practical, three recent changes driven into U.S. building codes by the U-M-led consortia have expanded the range of possible solutions for increasing power availability and reducing the greenhouse gases associated with individual building on-site generators:

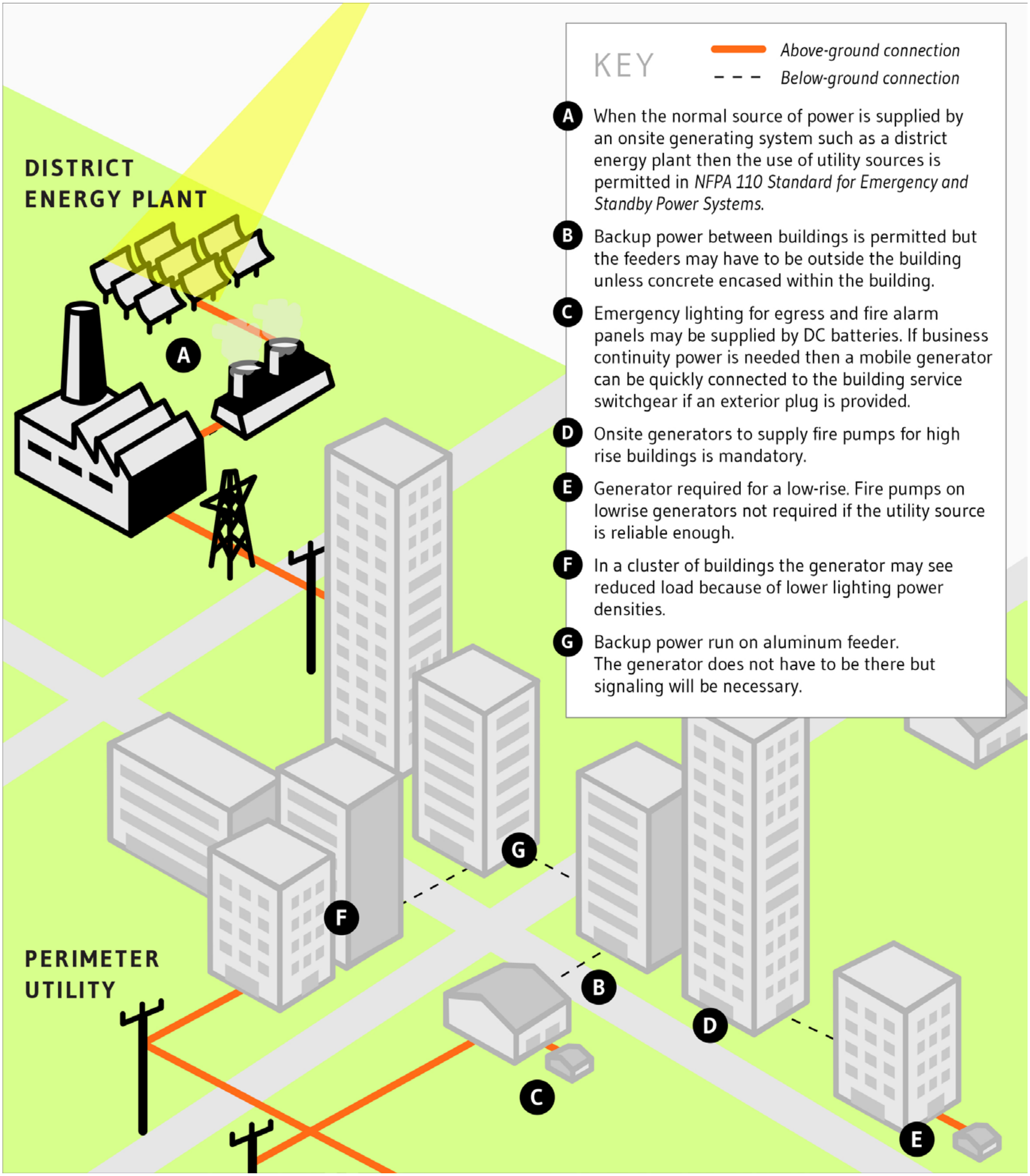
1. QUANTITATIVE RELIABILITY METHODS. Fault tree analysis, a top-down, deductive failure analysis in which an undesired system state is analyzed using Boolean logic to combine a series of lower-level events, can be applied to understand how systems can fail, identify the best ways to reduce risk or determine reliability, and make quantitative comparisons. Very few electrical engineers retained by architectural consultants have had training in these methods, which is a partial explanation for the missed opportunity to allocate capital more effectively. Even fewer architects are permitted to have a large enough view of a campus power system to even begin a discussion about how a perimeter utility supply might be more available than the best-maintained on-site generator. In any case, the technical literature now has a quantitative foundation for engineering a fire-pump supply circuit—one of the key decisions in any campus building project (Anthony et al. 2012).
2. ALUMINUM WIRING. Even though aluminum wiring has been approved for wiring buildings since the earliest days of the power industry, many electrical professionals will resist the use of aluminum as a conducting material for reasons that are largely hearsay. The use of aluminum for backup power changes the cost equation mightily—and is especially significant for research universities where the density of square footage and the paucity of green space prohibit the siting of on-site generators. The ability to run more backup power feeders longer distances to fewer generators can cut the cost of delivering backup power by two-thirds.
3. LOWER POWER DENSITY. While the trend toward lower power densities has existed for over 50 years, a change to the 2014 National Electrical Code by the U-M-led consortia recognized it and applied its consequences (see figure 1). The U.S. economy is now more dependent upon reliable power than ever before, but it can be supplied from a far greater number of smaller, more richly interconnected normal sources. If on-site generators are necessary, then many of them can be specified with lower kilowatt ratings, resulting in lower greenhouse gas and air pollution emissions because of their reduced power density (Anthony et al. 2012).

When just these three possibilities are applied either separately or together on one of the several hundred campuses with an on-site district energy source about one in five on-site generators may be avoided—*when the mission is emergency (life safety) power only*. The advantage in offset emissions is significant and has been proven in a real-world example (see sidebar 2). In many cases, the business continuity (optional standby) power mission may be met with the same system as long as the switchgear controls give priority to the life safety mission. Investment in the switchgear or in generators at the district energy plant may be a better use of capital if the multi-building funding problem can be solved.

A building power system that is 100 percent reliable is very expensive—and arguably does not exist in practical reality. Each additional "nine" of availability comes with a cost; in fact, there is often an exponential increase in cost as you move between "nines" of availability (moving from 99 percent availability to 99.99 percent availability, for example). For life safety purposes, three nines of availability is sufficient for the most common occupancy types in our industry. That means that the backup power is unavailable an average of 8.76 hours per year owing to end-to-end operational maintenance and testing of the system.

Risk trade-offs should be known and accepted in light of the financial impact of a power outage. Risk is highly subjective, and risk tolerance should always be an ongoing discussion among stakeholders. These discussions will often turn emotional (i.e., non-quantitative) very quickly. For example: Ask a public safety official about exterior lighting and he or she will want 30 footcandles of light on campus at night. Energy management and night-sky activists will think

Figure 1 **Conceptual Configuration of a Campus with Fewer On-Site Generators**



KEY

- 🟧 *Above-ground connection*
- - - - *Below-ground connection*

A When the normal source of power is supplied by an onsite generating system such as a district energy plant then the use of utility sources is permitted in *NFPA 110 Standard for Emergency and Standby Power Systems.*

B Backup power between buildings is permitted but the feeders may have to be outside the building unless concrete encased within the building.

C Emergency lighting for egress and fire alarm panels may be supplied by DC batteries. If business continuity power is needed then a mobile generator can be quickly connected to the building service switchgear if an exterior plug is provided.

D Onsite generators to supply fire pumps for high rise buildings is mandatory.

E Generator required for a low-rise. Fire pumps on lowrise generators not required if the utility source is reliable enough.

F In a cluster of buildings the generator may see reduced load because of lower lighting power densities.

G Backup power run on aluminum feeder.
The generator does not have to be there but signaling will be necessary.

SIDEBAR 2: EFFICIENT ENERGY SOLUTIONS IMPROVE PUBLIC HEALTH OUTCOMES AND RESILIENCE

by Patricia D. Koman, University of Michigan, School of Public Health

Energy needs for campus buildings pose sustainability and resilience challenges that should be considered alongside cost and other considerations. Efficient solutions may reduce the public health impacts of climate change and air pollution. Older backup energy systems may rely on significantly more polluting diesel generator units that were not designed for full load operation or high durability; these units may also be poorly maintained. Over the past decade, there have been order of magnitude changes in emissions profiles for engines above 130 horsepower (> 175 kW).

Even modern natural gas units can be improved upon, as demonstrated in a recent University of Michigan Athletic Campus example in which five individual building generators were replaced with a single utility source. The expected emissions reduction over the 30-year life of the project is approximately 10.8 short tons of nitrogen oxides, 806 pounds of particulate matter, 0.84 short tons of hydrocarbons, and 72 short tons of carbon dioxide (or 65 metric tons) based on about 1,500 kilowatts (five 300-horsepower CNG generators) operating 200 hours/year. This assumes negligible additional emissions from utility-produced backup.

Examining the emissions trade-offs for each situation is critical for improving sustainability from a public health perspective. Air emissions from backup generation units include particulate matter and nitrogen oxides, which contribute to ground level ozone or smog formation. Numerous health studies have linked particulate and ozone exposure to a variety of problems, including premature death from heart or lung disease; aggravated asthma, throat irritation, and congestion; decreased lung function and worsened bronchitis; and increased respiratory symptoms, such as irritation of the airways, coughing, or difficulty breathing (U.S. Environmental Protection Agency 2009, 2012).

Particulate matter has also been linked to cardiac endpoints such as nonfatal heart attacks and irregular heartbeat (U.S. Environmental Protection Agency 2009). Ground level ozone also can reduce lung function and inflame the linings of the lungs. Repeated exposure to ozone may permanently scar lung tissue (U.S. Environmental Protection Agency 2012). These effects may lead to increased school and work absences, medication use, visits to doctors and emergency rooms, and hospital admissions. Children are especially vulnerable to exposure to air pollution because their lungs and other systems are still developing (U.S. Environmental Protection Agency 2009, 2012).

Fortunately, many cost-effective technologies and strategies can be used to reduce emissions. The U.S. Environmental Protection Agency offers a simple calculator to estimate emissions, which can help campus planners determine the best air pollution control options for their unique situation: www.epa.gov/cleandiesel/quantifier/. As described above, if these technologies and strategies are widely adopted, significant energy and emissions savings can be achieved.

quite differently. The standards now call for a minimum of 1 footcandle, reflecting both a technical and cultural compromise that reconciles the competing requirements of safety and economy. Our question may be sharpened thus: How much are we willing to pay for backup power on a per-building basis when forced outages run along a continuum of 8 seconds to 8 minutes to 8 hours to 8 days?

CHECKLIST FOR PLANNERS AND ELECTRICAL ENGINEERS

Before sustainability and smart-grid activists roll in with their conceptions of the “Internet of everything” and the promise of load management with distributed, interactive sources, we need to do the simple things well. All the annual savings promised in the smart-grid *zietgeist* can be wiped out in a forced outage of less than a minute, possibly putting a cost impact onto the ledgers of the Risk Management department when catastrophic outages are covered by insurance. To make practical and risk-informed decisions, campus planners should ask the electrical engineers the following:

1. CAN THE NEAREST PUBLIC UTILITY SOURCE BE USED? As noted previously, on campuses where district energy systems are the normal source of power, public utility sources are permitted as long as the building is not a high-rise that needs a fire pump. Many public utilities have spot markets in which electrical load growth has stalled because of changes in the economy or the success of energy conservation projects. When a utility has stranded capacity in its municipal distribution system, utility sources for backup power are typically available. A utility source that is reliable enough to be the normal source of power is typically acceptable as a backup source of power. Anthony (2010) and Anthony, Harman, and Harvey (2013) provide guidance on how engineers can compare operational availability with respect to scheduled and forced outages to inform decisions about how to invest in the district energy plant.
2. CAN WE SUPPLY BACKUP POWER FROM AN ADJACENT BUILDING? There are cases in which two buildings in close proximity are supplied from separate buses in so-called “main-tie-main” switchgear architectures with automatic switching. In this case, the second building’s emergency power may be supplied from the first building’s power when analysis and operating experience can confirm availability of separate buses capable of providing the same availability of on-site generators. The long-term planning of campus distribution system development should consider the possibility that adjacent buildings can be supplied from distribution feeders on separate buses—either at the district energy plant or at downstream switching stations.
3. CAN WE USE AN UNDERLOADED GENERATOR 1,000 FEET AWAY? The economy of using aluminum wiring to cut the cost of running feeders by up to two-thirds makes it possible for the electrical designer to locate the generator at greater distances from the load, contingent upon switchgear and signaling. Control wiring must be run with the supply feeders. While testing and maintenance can be more complicated, overall such a system can provide greater reliability at lower cost when fuel availability and/or emission restrictions are present.

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The central feature of the idealized campus power delivery system in figure 1 is the district energy plant. Its role in reducing the number of downstream, building-specific, on-site generators should be plain. The degree to which investment that would have otherwise been sunk into the building-specific generator and instead allocated to the district energy plant to supply the backup power every time a new building comes on line is a delicate piece of financial engineering. Its solution, though site-specific and contingent upon analysis, operating experience, and the conditions of maintenance and supervision (which are typically fortuitous), holds the promise of solving site and emissions problems for, say, 10 buildings in a single, bold stroke.

Some of the difficulty in getting away from the one-generator-per-building model stems from how building projects have been traditionally financed—i.e., every department is, effectively, in charge of its own power reliability. As Max Storto suggests in sidebar 3, a revolving "green fund" could be set aside to accommodate the larger, longer-term engineering view that governs the way campuses develop. A green fund might be used to finance upstream switchgear architectures or district energy controls that behave in a way that reduces the number of generators in the next 10 buildings. Money on the order of $10,000 to $100,000 is a good start for a revolving fund that would finance the engineering of backup systems for, say, 10 buildings. While such projects do not have marquee titles like Smart Grid, they make all the other marquee buildings more sustainable and fit better into their campus space.

SIDEBAR 3: FINANCING THE FUTURE: HOW GREEN REVOLVING FUNDS CAN HELP INSTITUTIONS FINANCE ENERGY EFFICIENCY PROJECTS

by Max Storto, Sustainable Endowments Institute

The Rockefeller Foundation and Deutsche Bank Climate Change Advisors published a research study last year that found that $279 billion in retrofits across the residential, commercial, and institutional markets could yield up to $1 trillion in energy savings (DB Climate Change Advisors and The Rockefeller Foundation 2012). Although there has never been a study that quantifies the economic potential of energy efficiency upgrades on college and university campuses, this study shows that there is significant opportunity for energy conservation measures in numerous sectors, including higher education.

Reducing energy demand on college campuses through infrastructural upgrades will save money, mitigate carbon emissions, and decrease the need for large generators. Furthermore, improved energy efficiency practices will reduce the amount of energy that must be supported during blackouts. When college campuses invest in energy efficiency upgrades and simultaneously abandon the one-generator-per-building model as Mike Anthony advises, they are more prepared for frequent power outages. Additionally, efficiency retrofits that incorporate new technologies both modernize campus buildings to improve their habitability and require smaller backup generators.

Financing energy efficiency upgrades can prove challenging. Traditionally, college campuses have allocated a portion of their yearly operating budgets for sustainability projects, which can be an effective approach. However, creating a separate revolving fund that earmarks capital specifically for such projects can leverage more opportunity than annual allocations. Green revolving funds invest in energy efficiency projects in order to reduce energy consumption and then reinvest the monetary savings into future cost-saving projects. Despite the economic potential of energy efficiency retrofits, universities continue to consider such expenditures as "expenses." In reality, these projects should be considered "investments" because they can strongly reduce the burden on campus operating budgets. A green revolving fund can free up capital to even finance a new and improved campus generator through the energy savings generated by existing efficiency projects.

CONCLUSION

The possibilities for contributing to our industry's sustainability ambitions while also adding value to the power infrastructure originate from a 17-year effort led by the University of Michigan to use the economic footprint of the education facilities industry to raise expectations for innovation and value among its suppliers. The effort is not unlike what the automobile, airline, and retail industries have done to aggressively manage cost and meet environmental goals. Our industry is just too large a stakeholder to not use every tool available to meet the same goals.

While the study unit for this article was electrical power only, we have had success like this in several other infrastructure technologies that prove the benefit of assertive advocacy in technical standard development. We have the success of the railroad industry in standardizing railway widths and the failure of the cell phone industry to standardize on chargers as object lessons in the significance of technical standards. To what degree can safety and sustainable infrastructure benefit from standards advocacy by the public non-profit User interest on the same scale as the private for-profit Producer interest? To what degree does it fail in its mission if it does not try?

REFERENCES

Anthony, M. A. 2010. Case Study 5: Governmental Facility—Mission Critical. In *Sustainable On-Site CHP Systems: Design, Construction, and Operations*, ed. M. Meckler and L. Hyman, 367–86. New York: McGraw-Hill.

Anthony, M. A., R. Arno, N. Dowling, and R. Schuerger. 2012. Reliability Analysis for Power to Fire Pump Using Fault Tree and RBD. *Industrial & Commercial Power Systems Technical Conference (I&CPS), 2012 IEEE/IAS 48th*, 1–7. Retrieved November 26, 2013, from the World Wide Web: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6229612&contentType=Conference+Publications&searchField%3DSearch_All%26queryText%3DReliability+Analysis+for+Power+to+Fire+Pump+Using+Fault+Tree+and+RBD.

Anthony, M. A., R. Arno, P. S. Saba, R. Schuerger, and M. Beirne. 2011. Reliability Engineering Applied to Critical Operations Power Systems (COPS). *Industrial & Commercial Power Systems Technical Conference (I&CPS), 2011 IEEE*, 1–8. Retrieved November 26, 2013, from the World Wide Web: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=5890892&contentType=Conference+Publications&searchField%3DSearch_All%26queryText%3DAnthony+Arno+Schuerger.

Anthony, M. A., T. L. Harman, and J. R. Harvey. 2013. Rightsizing Electrical Power Systems in Large Commercial Facilities. *Industrial & Commercial Power Systems Technical Conference (I&CPS), 2013 IEEE/IAS 49th*, 1–7.

DB Climate Change Advisors and The Rockefeller Foundation. 2012. *United States Building Energy Efficiency Retrofits: Marketing Sizing and Financing Models*. Retrieved November 26, 2013, from the World Wide Web: www.rockefellerfoundation.org/uploads/files/791d15ac-90e1-4998-8932-5379bcd654c9-building.pdf.

IEEE Standards Association. 2012. *IEEE 1366-2012 – IEEE Guide for Electric Power Distribution Reliability Indices*. New York: IEEE.

NFPA. 2013. *NFPA 110: Standard for Emergency and Standby Power Systems*. Quincy, MA: National Fire Protection Association.

U.S. Environmental Protection Agency. 2009. *Integrated Science Assessment for Particulate Matter* (Final Report). Washington, DC: U.S. Environmental Protection Agency. Retrieved November 26, 2013, from the World Wide Web: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546.

———. 2012. *Integrated Science Assessment of Ozone and Related Photochemical Oxidants* (Third External Review Draft). Washington, DC: U.S. Environmental Protection Agency. Retrieved November 26, 2013, from the World Wide Web: http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=242490.

ADDITIONAL READING

Anthony, M. A., and J. Andre. 2013. Re-Imagining Safer Power Systems in Education Facilities Industry. NEMA *Electroindustry*, May, 24–25.

Anthony, M. A., and P. Kempf. 2013. Disrupting the National Electrical Code. *Facilities Manager*, March–April, 42–43.

Anthony, M. A., P. Ling, and J. Meijer. n.d. The Safety and Economic Benefit of Reduced Power Design Densities Permitted in the 2014 National Electrical Code. Paper accepted for presentation at the May 2014 IEEE meeting.

IEEE Standards Association. 2007. *IEEE 493-2007 – IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems*. New York: IEEE.

AUTHOR BIOGRAPHIES

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