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Innovation for Our Energy Future

Solar Secure Schools: Strategies and Guidelines

October 2004 — April 2005

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Executive Summary

On-grid applications of solar power have eclipsed traditional grid-independent applications in recent years. As a result, the overall solar power market has grown consistently by around 30% per year, and the global solar industry's annual sales are in the $10 billion range. Most on-grid solar power applications use the roofs of homes and commercial buildings as platforms; meanwhile, in the United States, large numbers of scale model solar power systems are being deployed at schools by electric utilities for promotional and educational purposes.

Can school-based solar power systems provide more tangible value? In 2002, the U.S. Department of Energy and the National Renewable Energy Laboratory envisioned a national network of solar-powered, school-based emergency centers. A previous report[1] considered the technological, economic, and policy considerations of this initiative and identified the need for financing strategies and decision tools for school boards and administrators.

Schools are used routinely in sheltering vulnerable populations during and after major disasters such as hurricanes, terror attacks, and local and regional grid failures. The previous report concluded that shelters operating without power are neither healthy nor safe. An "energy secure school" would be protected against grid and natural gas supply disruptions, and a "solar secure school" would be insulated from significant unplanned increases in its annual energy bill.

Solar secure schools are not only technically feasible but also economically justified when grid electricity prices are high and volatile or schools are shut down by grid power outages more than once every 10 years. Solar power prices and grid electricity prices are trending strongly in opposite directions, so solar secure schools soon will be an attractive cost control and public safety strategy in most states.

The present effort has produced a simple step-by-step process that school officials can use to assess their energy security options. The solar power industry, in cooperation with federal and state clean energy R&D programs, should emphasize development of products that allow seamless, plug-and-play integration of basic solar secure school subsystems, including power conversion and energy storage. The ultimate plug-and-play option for solar secure schools may be the "plug-in hybrid" school bus, providing prepaid plug-and-play energy storage that has the important advantages of being portable and essentially maintenance free.

Options are emerging to solve the capital budget allocation problem. School budgets, both capital and operating, are typically strained; a third of all school construction and renovation bond issues are rejected by voters. Solar service companies are emerging that offer attractive solar electricity prices and take full long-term responsibility for operation and maintenance of school-based solar power in return for use of the school roofs as solar power array mounting platforms.

Solar electricity prices offer the additional attraction of being fixed for a decade or two, during which grid electricity prices will continue to escalate unpredictably with the price of fossil fuels. More aggressively managed school districts will be able to maximize electricity cost savings by self-financing their solar power needs, especially in states that adopt preferential "feed-in" tariffs that guarantee long-term purchase prices for solar electricity fed into the grid. Such long-term solar electricity purchase arrangements greatly facilitate access to low-interest private financing of solar power systems and are, therefore, already widely employed in European countries.

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[1] See Appendix A for a summary of the full report.

Introduction

School-based solar power systems can be upgraded to deliver emergency power when the grid is down for extended periods. Other emergency generation solutions (e.g., fuel-based emergency generators or grid-charged energy storage) have costs in the same range and are limited by their fuel or electricity storage capacity, among other drawbacks. In 2004, the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) initiated a project to develop guidelines and design specifications for low-cost, prepackaged photovoltaic (PV) solar power systems on schools to enable the schools to be used as community emergency centers. The first phase of this work pointed to several key steps toward a national network of energy secure schools, including the following:

- Recognizing PV/battery hybrid options in applicable guidelines and standards
- Developing and disseminating decision tools for school boards, school business managers, and facility managers, along with procurement guidelines and technical specifications to support deployment
- Providing technical demonstrations of basic system sizes and configurations for upgrading school-based solar power systems for emergency power purposes
- Designing incentives specifically to encourage early consideration of school-based solar power systems and related reliability upgrades
- Initiating collaborative R&D to provide technology base support and focus industry attention on new products necessary to make schools energy secure in the most cost-effective manner
- Raising awareness of the role solar power will play in the future energy supply mix and solar power's ability to meet critical energy needs when fuel supplies and electricity infrastructure are disrupted.

As important as they are, these matters are moot unless strategies are in place to evaluate and finance solar power on schools and maximize its energy security benefits. Applying such strategies with the help of the guidelines and specifications envisioned by NREL will result in energy secure schools. This report outlines the strategies and provides general guidance and specifications for use by school boards and administrators.

What Are Energy Secure Schools?

Energy security is a term originally applied in a national context; it referred to vulnerability to disruption in supplies of imported fuel. The oil shocks of the 1970s raised concern about energy security and led to President Nixon's "Project Independence" and the creation of a strategic petroleum reserve. More recently, the United States began importing liquefied natural gas as well as oil, while global demand for oil and natural gas has increased against a backdrop of war and terrorism affecting fuel-rich regions. The Northeast U.S. blackout of 2003 and comparable grid disruptions in other industrial countries served as reminders that energy security depends on electricity infrastructure as well as fuel supply.

The expansion of critical loads through the addition of electricity-dependent technologies, including computers, has highlighted the dependence of organizations and facilities on reliable power. In the wake of recent blackouts and security scares, some cities are now pressing facility executives to have backup generation available to power more than just safety and security systems, e.g., for operational continuity of low-rise structures such as schools. This is a legitimate dimension of the original concept of energy security.

The concept of energy security can be expanded further by considering price. Energy supplies are not secure if they become unaffordable. The legitimacy of this aspect is underscored by the California electricity crisis, during which retail grid electricity prices were essentially unstable and threatened regional economies and electricity customers. By restructuring the U.S. natural gas and electricity industries to introduce competition and promote economic efficiency, regulators also have made the industries less responsible for energy security and less able to deliver it.

Schools are affected by all dimensions of energy security, from the effects of global fuel price instability to local energy infrastructure disruptions and local utility price trends and swings. Of all energy users, schools are among the most vulnerable to energy insecurity. Without electricity, schools are not safe for work or study. With no way of generating extra revenues to pay for unexpected costs, schools must cut programs and staff when energy bills rise unexpectedly.[2]

Typically, some schools in each community are designated as emergency shelters. Emergency shelter operation in the wake of disasters usually coincides with short-term or extended grid failure. In a previous report[3] it was established that emergency shelters operating without power are neither healthy nor safe. An energy secure school would be protected from grid and natural gas supply disruptions and insulated from significant unplanned increases in its annual energy bill.

Are Energy Secure Schools Technically Feasible?

To qualify as energy secure, schools must have stable energy costs and the ability to operate normally when external energy supply is disrupted. U.S. energy consumers, including schools, have enjoyed relatively stable energy costs throughout most of the 20th century. The technologies that made this possible are still available, and new options such as solar power are now available as well. Technically mature on-site power systems are now options where operational continuity during short-term loss of external energy supply is a critical need. On-site solutions include fuel-based emergency generators and battery-based uninterruptible power systems (UPS).

Properly sized, installed, and maintained, these on-site solutions work well to buffer energy users from grid outages ranging from less than a second to a few hours with UPS and even up to a few days with emergency generators with dedicated or uninterruptible fuel supplies. However, they have the basic disadvantage of depending on external sources of electricity or fuel, for recharging in the case of UPS and for extended operation in the case of emergency generators. By contrast, the technical maturity and reliability of terrestrial solar power systems is now well established, as is the preference for solar power in off-grid applications requiring long-term uninterruptible power. For these reasons, and others,[4] where solar power can be justified economically it should be configured not just to supply bulk electricity but also to ensure the supply of electricity when local grid operation is disrupted for extended periods.

How Can Solar Power Make Schools Energy Secure?

A previous report[5] explained that a school with a PV array of any size on its roof can be upgraded by adding energy storage and appropriate power conversion and control equipment so that, when the grid goes down, at least some building circuits and critical equipment remain operable. The economics of basic solar power systems and the costs of an appropriate energy security upgrade were outlined, but technical choices and specifications—i.e.,

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[2] For example, "Everett School District (Washington) cut its electricity consumption 12 percent in 2000 but still had a nearly 100 percent increase in power costs. To pay the bill, it cut the school budget by $1 million, equal to annual spending for textbooks or the salaries of 15 teachers." Source: Hardin, B. (March 1, 2005). "Utility Exposes Enron Greed at its Core." *Washington Post*.

[3] Braun, G.W.; Varadi, P.F; Thornton, J. (In review). *Energy Secure Schools: Technology, Economic and Policy Considerations*. National Renewable Energy Laboratory.

[4] For example, underground fuel storage for emergency generators is subject to regulatory requirements pertaining to spill containment, release detection and response, tank abandonment and removal, and so forth. Source: University of Maryland Department of Environmental Safety (May 2003). *Underground Storage Tanks: Motor Fuel, Used Oil And Emergency Generators USTs*. Safety Fact Sheet, www.des.umd.edu/compliance/factsheet/undergroundtanks.html.

[5] Braun, G.W.; Varadi, P.F; Thornton, J. (In review). *Energy Secure Schools: Technology, Economic and Policy Considerations*. National Renewable Energy Laboratory.

"how can solar power make schools energy secure?"—were not discussed. Today's answer and tomorrow's answer will differ. The menu of relevant energy storage choices will continue to expand. Meanwhile, solar power equipment costs will continue to drop, even as fossil fuel prices continue to escalate, driving the price of grid electricity steadily higher.

Basic Solar Secure School System Functionality

The basic solar secure school system must do the following:

- Offset grid electricity purchases, especially when grid electricity prices are high
- Provide emergency power sufficient to support routine school operations during a grid outage of any duration.

Sizing of the basic solar secure school system is driven by three factors:

- Economies of scale of the basic solar power system
- The school's nominal peak power demand and daily energy use in normal operation
- The school's energy use when operating to conserve electricity without limiting operation.

Efforts are also underway to use demonstration-scale solar power systems for educational purposes.

Scale Economies

Commercial rooftop solar power project costs depend on project scale. Solar power modules are a major cost driver for any solar power system, and collector array cost typically scales directly with system size. However, other cost elements, including DC-to-AC power conversion equipment, project development, engineering, and installation fees, do not scale directly with system rating. The result is that small-scale solar power systems can cost 50%–100% more per installed kW than large ground-based or commercial rooftop systems.[6] Table 1 suggests that there are significant economies of scale even in the range of sizes that would significantly reduce or avoid grid electricity charges entirely. In the near future, size may be the difference between school-based solar power that is affordable and solar power lifecycle costs that exceed the cost of avoided grid electricity purchases. Accordingly, the basic school-based solar power system should be sized to make full use of suitable roof area. For typical U.S. elementary, middle, and high schools, this entails rooftop solar power arrays with ratings of 100–500 kW.

Table 1. Scale Effects on Commercial Rooftop Solar Power System Costs

System Size (kWac)	10-50	50-150	150-500	500-1,000
	$/kWac			
Installed Cost - Low (1)	7,500	6,750	6,450	6,250
Installed Cost - High (2)	9,000	7,750	7,100	6,500

Notes:
1. The low end of the cost range is based on experience of nationally active companies offering solar service to low-rise commercial building owners in the United States.
2. The high end of the range includes allowances for special site preparation, engineering, etc., and other contingencies driven by local requirements and conditions.

Peak Power Demand

During emergency operation, a school-based solar power system can be made functionally equivalent to natural gas fueled emergency generators already being deployed in some schools. The emergency generators specified for

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[6] The majority of current school-based systems are at the high end of this range because they involve small, customized installations and equipment purchased through distributors and local dealers.

Montgomery County, Maryland, public schools are capable of carrying loads of 30–100 kW depending on whether the school is an elementary school (small), middle school (medium), or high school (large). They are fueled with natural gas from separate, uninterruptible natural gas lines. A solar power system will be able to support a few hours of operation at full load on an average day. Depending on the season, its actual peak output during a typical day may not approach its annual peak output. Because of this, and because part of the energy delivered by the solar power array must be stored for use earlier and later in the day, the solar power system should have a peak output approximately three times the above-specified loads, i.e., 100–300 kW, depending on the type of school.

Energy Use

A school's energy use during normal operation will result in a load factor of 50% or less, depending on the type of school and the season. At a 50% load factor, a school with a peak demand of 100 kW would consume 1,200 kWh daily. A 300-kW solar power system would deliver roughly this amount on average over a year depending on location. Assuming roughly half of the daily energy use could be served directly from the solar power array, energy storage capacity must be minimally capable of storing the other half for delivery earlier and later in the day. This suggests storage system sizing of 3–6 kWh per kW of rated solar power system output. For example, a storage system for a 300-kW solar power system roughly should be sized to store 900–1,800 kWh of electricity.

Not all of the charging electricity is recovered as useful electricity when a battery is discharged. Up to 30% is lost to power conversion inefficiencies and other loss mechanisms. However, a UPS battery would be fully charged when a grid outage occurred, and the solar power system would only need to replenish daily use during an extended grid outage; thus, round trip efficiency, although technically important, is not economically important.

Engineering: Are Energy Secure Schools Technically Feasible?

Current Technical Solutions: Full Energy Security

There are significant numbers of medium to large (30 kW to several MW) grid-tied solar power systems in operation, particularly in Europe and California. Experience to date with this scale of solar power has demonstrated a strong market preference for packaged solutions. However, there are no packaged grid-interactive system offerings at this scale that also come with energy storage. Solar power system integrators are technically qualified to design and build large systems incorporating battery energy storage, but their related experience is limited, mostly to large, stand-alone (off-grid) PV/battery hybrid systems or smaller, grid-tied PV/battery hybrid applications. Custom engineering would be required for large, grid-tied PV/battery hybrid systems. For this reason, equipment and installation costs for large, grid-tied PV/hybrid systems likely would be elevated, especially if the basic solar power system is installed first and later upgraded and reconfigured to provide energy security. One key factor driving customization costs is the lack of off-the-shelf power conversion units with ratings exceeding 5 kW that also meet the following specifications:

- Capability for battery charging from the solar power array or the grid
- Capability for AC power generation from multiple DC sources, i.e., batteries and the PV array
- Capability for two modes of AC power generation:
  - Grid-tied from the PV array (normal)
  - Grid-isolated from the PV array, the battery, or both (emergency).

Once such units are available, capturing the full economic benefit of a large, grid-tied PV/battery hybrid system will in many cases require a third mode, i.e., grid-tied from the PV array, the battery, or both for peak shaving purposes.

Technology and components to fill the abovementioned gaps in current packaged solar power system offerings are available from two sources: the UPS industry and the emergency generator industry. An important caveat: highly engineered equipment intended for a specific purpose must be applied to other purposes with considerable care, even when the application is permissible without voiding product warranties.

Large-scale UPS offered by several manufacturers can be a suitable complement to the basic solar power system. They are available over a wide range of power ratings, battery capacities, and battery types and interactivity. Their costs range widely from relatively low-cost systems capable only of operating in a grid-isolated mode to those providing seamless automatic transfer of loads between UPS and grid.

In combining off-the-shelf UPS equipment with solar power systems, there is still one gap to be filled, arising from the fact that the controls and inverters supplied as a part of UPS include no provision for battery charging from a DC source such as a solar power array. Various configuration options are possible to fill this gap, but suitably large PV charge control products are either unavailable or in very limited production; power ratings of charge control components for typical off-grid PV/battery hybrid systems are well below the peak output of an economically optimal school-based solar power system.

In summary, the product development gap facing energy secure schools is modest: mature and readily available power conversion products to integrate, operate, and optimize the interplay between large solar power arrays, large battery banks, and the grid are not yet available, and there is as yet little market pull to encourage investment in new product offerings. Most significantly, the national R&D programs addressing solar power technology and battery energy storage technology are not addressing, individually or collaboratively, the need for plug-and-play functionality for all elements of battery-coupled, grid-tied solar power systems. National solar programs in the United States and elsewhere are driven by a vision of solar power as a bulk energy source, not as an enabler of fully energy secure buildings. This can change, and the first step would appear to be the creation of a technology and deployment roadmap that recognizes and exploits the symbiosis of solar power and energy storage. Examples of the economic optimization opportunities involved were highlighted by Hoff, et al.[7]

Current Technical Solutions: Limited Energy Security

Presently, significant numbers of schools are being equipped with small-scale (hundreds at 1–10 kW) or medium-scale (tens at 10–50 kW) solar power arrays and grid feed-in inverters. These installations are funded via targeted grants and rebates typically available for a year or two in a given utility service area. They can be upgraded to provide back-up power during grid outages by adding batteries and an off-the-shelf 1–5 kW “battery-based” inverter of the sort available from at least two U.S. inverter manufacturers and their distributors.[8] For applications larger than 5 kW, it is possible to deploy multiple power conversion units each powered by a portion of a large solar power array and a large battery bank. With investment in custom engineering and site electrical work, multiple circuits within a school can be kept energized for emergency purposes, even if solar power system and battery capacities are insufficient to support normal operations.[9]

The prospect for sustainable deployment of such sub-optimally-sized solar power systems on schools in the United States is limited. More readily accessible markets are currently available to the U.S. solar power industry, and school maintenance and renovation budgets typically do not have the flexibility to pay for energy security

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[7] Hoff, T.E.; Perez, R.; Margolis, R.M. (2005). “Maximizing the Value of Customer-Sited PV Systems Using Storage and Controls.” Clean Power Research, www.clean-power.com/research/customerPV/OutageProtection_ASES_2005.pdf.

[8] Brief descriptions of several leading grid-tied PV inverters are provided in the following article: Schwartz, J. (April/May 2005). “What’s Going On – The Grid?” *Home Power Magazine*.

[9] A demonstration of this strategy has been proposed for modification of part of the Odyssey Charter School in Palm Bay, Florida, to serve as an energy secure community shelter. Source: Young, W. Private Communication. Florida Solar Energy Center.

upgrades of school-based solar power systems. Accordingly, more detail regarding how to consider and specify energy security upgrades for these systems is not offered here. Generally, the most favorable scenario for funding such upgrades is to include them in local mitigation strategies for which budgets typically become available within a year or so after a disaster strikes.[10]

Special cases deserving attention in the context of disaster preparedness have been covered in a previous report.[11] States that designate and equip schools as public crisis centers and disaster relief shelters should consider upgrading existing solar power system arrays on these schools to supply critical loads during extended population sheltering operations. Special consideration should be given to schools designated as "special needs" shelters, i.e., shelters intended for medical care of elderly or chronically ill persons. Proper care of chronic illnesses, for example, typically relies on equipment powered by electricity, e.g., for dialysis and treatments of chronic respiratory ailments.

Future Technical Solutions: Full Energy Security

In the longer term, an emerging option for large, school-based solar power systems is the use of "plug-in" hybrid electric vehicles (HEVs) as portable energy storage systems during extended grid outages.[12] Appendix B discusses how plug-in HEVs can facilitate fully solar secure schools. For example, fleet vehicles are envisioned as an early plug-in HEV market; hybrid school buses could include their own sun-powered battery charger.

The most important aspect of the connection between HEVs and energy secure schools may be the size of the market for HEVs and the technology investment it justifies. The HEV market is real, and the market forces driving it are rapidly gathering. Oil prices have peaked again and are now the subject of Congressional concern.[13] Gasoline prices have pushed beyond $2 per gallon in the United States, and many urban areas of the United States and elsewhere face daunting public health issues related to vehicle emissions. HEVs have imbedded battery storage. They come with or can be readily equipped with the power conversion and control equipment needed to accept energy from a solar power array, store it, and deliver it on demand to a building or any AC circuit within a building. This readily realized potential creates a new route on our nation's overall technology roadmap. Such a route bypasses the issues that have limited deployment of on-grid energy storage in the past. Specifically, low-maintenance, safely enclosed batteries in HEVs overcome the main obstacles to on-site stationary battery systems, i.e., high initial cost of equipment used only in emergencies, requirements for routine maintenance and periodic battery replacement, and special attention to ensure personnel safety.

Economics: Are Energy Secure Schools Affordable?

The affordability of energy secure schools depends on the cost and economic value of the basic solar power system as well as the incremental cost and value of enhanced capability ensuring operational continuity during

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[10] The local mitigation strategy (LMS) is a plan that seeks to reduce or eliminate damage due to storms or other disasters before they occur. For example, in Florida, the primary mechanism in the development and implementation of the LMS is the LMS Committee. The LMS Committee is made up of various county, state, and municipal officials as well as representatives from private and nonprofit agencies. Working together to represent all interests in the community, the LMS Committee identifies potential mitigation projects (e.g., retrofitting existing buildings for use as hurricane shelters), prioritizes such projects, and, together with officials from the State Department of Community Affairs, oversees their completion. Limited grant funding is made available from the State of Florida, with the goal of reducing potential economic losses by building disaster-resistant communities. Source: Young, W. Private Communication. Florida Solar Energy Center.

[11] Braun, G.W.; Varadi, P.F; Thornton, J. (In review). *Energy Secure Schools: Technology, Economic and Policy Considerations*. National Renewable Energy Laboratory.

[12] Hakim, D. (April 2, 2005). "Hybrid-Car Tinkerers Scoff at No-Plug-In Rule." *New York Times*.

[13] Bartlett, R. (March 14, 2005). "Peak Oil Presentation to the U.S. Congress [Video]." C-SPAN, www.energybulletin.net/5080.html.

extended grid outages. For illustrative purposes, this section compares generic costs and values for a range of assumptions that may be valid for U.S. schools over the next decade. Actual costs and values, however, will not only change with each passing year but also will vary from school to school, depending on school size, location, grid electricity costs, vulnerability to extended grid outages, and plans and provisions for use as community emergency shelters. The guidelines provided in Appendix C are intended to help school officials combine information from their own operating experience with the following generic cost information to determine whether investments in solar secure schools are prudent.

Operational continuity requires a source of electricity roughly equivalent to the local grid during periods when the grid is disrupted for extended periods. A relatively large solar power system is required for this purpose. Its cost cannot be justified based on the energy it delivers during emergencies, so its affordability must be assessed based on whether the electricity purchases from the grid that it offsets are worth the investment.

School-Based Solar Power System Affordability

The basic parameters of commercial rooftop solar power economics and finance are installed cost and annual electricity production (i.e., avoided grid electricity purchases).

System installed cost

Installed cost depends on local construction costs and solar competencies of local engineers and contractors. More importantly, it depends on array mounting and orientation details as well as overall project scale and timing. Scale dependency and timing aspects are roughly quantified in the following tables. Basic solar power system installed costs currently vary from as low as \$6,000/kWac for large school-based systems to as much as \$9,000/kWac for smaller retrofit systems on schools in the 10–50 kWac range. The latter systems, while unable to support full school operations on an ongoing basis, can be configured to power critical loads when the local grid is out of service. System costs are expected to continue on the well-established downward path based on technology improvements and economies of higher-volume component manufacturing. Table 2 summarizes the outlook for solar power costs by making simplifying assumptions about system size, cost of capital, and rate of equipment cost reduction. The table shows the effect of conservative assumptions about expected equipment price trends, e.g., annual average price reductions in the 5% range consistent with historical experience. It shows that, depending on solar resource quality and cost of capital, solar power costs are already in the range of economic competitiveness or will be within the next 10 years in most cases. Meanwhile, the cost of upgrading the basic solar power system with enough battery capacity to store half the system's average daily output adds only 5%–15% to the system cost.

Table 2. Current and Projected Solar Power Costs, 2005–2015

		2005	2010	2015
Resource Quality	Capital Charge	**Energy Cost**		
kWh/kW	%/year	**($/kWh)**		
2,000	10	$0.33	$0.25	$0.20
1,200		$0.54	$0.42	$0.33
2,000	5	$0.16	$0.13	$0.10
1,200		$0.27	$0.21	$0.17
		2005	**2010**	**2015**
Resource Quality	Subsystem	**Installed Cost**		
kWh/kW		**($ x 1,000)**		
	Solar Power	$1,950	$1,500	$1,200
2,000	Battery Storage	$200	$200	$200
1,600		$160	$160	$160
1,200		$120	$120	$120
Assumptions: *2005$* *300-kWac solar power system* *2005 installed cost = $6.50/Wac* *Cost reductions @ 5%/year* *Installed battery cost = $200/kWh*				

Avoided grid electricity purchases

In the commercial rooftop solar power economic model, avoided electricity purchases represent a cost saving attributable to the solar power system, a form of virtual revenue. Commercial electricity prices vary regionally but are typically the sum of multiple components captured in the form of "fixed charges," reflecting the cost of operating the utility system on a continuous basis, "fuel charges," reflecting the cost of fuel burned in power plants, and "demand charges," reflecting the incremental cost of meeting demand during higher-use periods. Currently, U.S. commercial building owners pay an annual average rate of around $0.1/kWh, which includes base energy generation and delivery charges as low as $0.05/kWh and incremental additional charges as high as $0.20/kWh during peak demand periods. Actual average electricity prices applicable to schools are presented in Table 3 for states where disasters or power grid disruptions have affected school operations in recent years. There is significant variation, notably Hawaii's prices ranging 50% above the national average, reflecting the state's oil dependence and limited investment in renewable energy. In locations where utilities experience a peak demand in the summer daytime hours, avoided costs attributable to a commercial rooftop PV system will be higher than in other locations because of the good match between solar electricity delivery and building energy use. Such a good match is illustrated in Appendix D.

Table 3. Historical Grid Electricity Costs for Commercial Customers, 1999–2003[14]

	California	Florida	Hawaii	Maryland	New Jersey	New York
Year	**Cents/kWh**					
1999	10.05	6.22	12.74	6.82	9.74	11.19
2000	10.25	6.25	14.81	6.55	9.14	12.65
2001	12.49	7.08	14.81	6.42	9.19	12.98
2002	13.22	6.64	14.11	6.09	8.87	12.46
2003	12.19	7.13	15.02	6.95	9.25	12.93
2004 (2)				9.04		
Mean	**11.64**	**6.66**	**14.30**	**7.01**	**9.24**	**12.44**
Range	3.17	0.91	2.28	2.95	0.55	1.74
Range - % of mean	27%	14%	16%	42%	6%	14%
Volatility index (1)	**5%**	**3%**	**3%**	**8%**	**1%**	**3%**

Notes:
1. The volatility index is calculated by determining the maximum, minimum, and average electricity prices for each of the preceding 5 years and dividing the difference between the maximum and minimum by five times the average. The index is a rough measure of the expected future annual percentage change.
2. 2004 Maryland prices are assumed to be 30% above 2003, based on published rate increase summaries by PEPCO.

Table 3 includes a measure of price variation among states and price volatility, quantified by determining the maximum, minimum, and average electricity prices for the preceding 5 years and dividing the difference between the maximum and minimum by the average. The use of data from 2003 and earlier may in some cases understate the volatility index in general and especially for states emerging from electric utility restructuring. For example, the volatility index for Maryland would be in the same range as for other states if pre-2003 data were used to calculate it, but using 2004 data provides a strikingly different perspective.

This seeming anomaly can be explained simply. During the recent wave of restructuring across the United States, a typical approach was to freeze the bulk energy component of retail electricity prices during a 4- or 5-year "transition period," creating a period of price stability typically followed by major electricity rate increases. For example, in Washington, D.C., and its Maryland suburbs, Pepco's fixed price generation component of bills for commercial customers in Pepco's service territory expired on July 1, 2004. As a result, small commercial customers' total bills increased approximately 13%, medium-sized commercial customers' (e.g. schools) bills increased approximately 25%–30%, and large commercial customers' bills increased approximately 48%–57%. Pepco attributes these increases to a 112% increase in the price of coal since 2000 and to significant increases in other power plant fuels as well (e.g., natural gas). In these and other states, the prevailing pattern of expanding electric generation capacity by adding natural gas fueled power plants, combined with recent upward swings in wholesale natural gas prices, has also driven significant recent increases in retail electricity prices.

Deciding How to Manage Electricity Price Risk

As discussed in the preceding paragraph, grid electricity suppliers are subject to major cost uncertainties, particularly related to their fuel and wholesale electricity purchases. Therefore, they typically will not guarantee stable forward pricing unless forced to do so by their regulators. Even then, the guarantee period is typically 5 years or less. Future electricity costs are much more difficult to forecast than in the past because in many cases a major portion of a school's electricity bill is no longer subject to economic regulation. For example, a school system in Everett, Washington, experienced a 100% increase in its annual electricity bill during the recent

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[14] Energy Information Administration, www.eia.doe.gov/cneaf/electricity/epa/average_price_state.xls.

California electricity crisis and responded by cutting its electricity use by 12% and its school budget by $1 million.

In general, schools have no way of securing stable electricity prices from their usual suppliers (i.e., electric utilities) because the utilities themselves are subject to increasing cost volatility. The best step a school system can take is to assess the likelihood and level of grid electricity price volatility using analysis of the sort illustrated in Table 3, and then review price stabilization options, including solar power. Table 4 uses the volatility index calculation illustrated in Table 3 to indicate which price stabilization option might be appropriate in a particular situation. For example, applying Table 4 to the price volatility information in Table 3 suggests that Maryland's 8% price volatility is in the unacceptable range. Depending on 2004 data for other states, at least one other state, California, can at best claim minimum price stability. Major school districts in California are doing exactly what the guidance in Table 4 suggests: evaluating long-term solar electricity purchases now.

Table 4. School Energy Price Stability Levels

Energy Cost Stability Level	Indicators	Stabilization Options
Maximum	Stable grid electricity prices (volatility index < 2%)	Secure long-term grid electricity supply contract if available
Intermediate	Variable grid electricity prices (volatility index 2-4%)	Evaluate energy efficiency investments having < 5-year simple payback now
Minimum	Highly variable grid electricity prices (volatility index 4-6%)	Evaluate solar electricity purchase within next 5 years
Unacceptable	Unstable grid electricity prices (volatility index > 6%)	Evaluate long-term solar electricity purchase now

Note: The volatility index is calculated by determining the maximum, minimum, and average electricity prices for each of the preceding 5 years and dividing the difference between maximum and minimum by the average.

Economic Value of Solar Secure Power

For ethical and liability reasons, the private sector has become much more attentive in recent years to providing a safe work environment for employees. Safety has become a top priority for many major corporations and is equally important for children and teachers. Recognizing the safety and operational continuity value of reliable electricity, some school systems equip their buildings with emergency generators. Although many do not, with more and more critical automated systems dependent on electricity, it is reasonable to expect full back-up power capability for schools to become the standard rather than the exception as it is now. How long it will take to reach a tipping point in this direction is unknown. Looking only at the direct economic cost to a school system of sending students home when the power goes out or closing schools until power is restored, the cost of emergency power may be difficult to justify. Calculating the indirect cost to the local economy of the ripple effect (both safety and economic) of a community reallocating its resources to care for children while its schools are unexpectedly closed, might give a different answer. For purposes of rough analysis, the cost of operating the school can be used as an indicator of the economic value of operating the school.

It is well known that the grid is interruptible. What is not well known is that grid power reliability varies substantially even within the same utility service area, i.e., some electricity customers experience frequent or extended outages and others do not. The substantial variation in grid reliability depends on technical factors typically invisible to a school district and its facility managers. These include the general age and condition of regional and local transmission and distribution infrastructure, funding and technical adequacy of related maintenance programs, circuit and equipment loadings, vulnerability to damage by accidents and storms, and, most significant and least understood, levels of redundancy and ability to switch loads from one substation or feeder to another. Typically, reliability “is what it is” unless the grid customer is willing to consider paying for equipment upgrades, redundant connections, or both. These options typically provide improved but not full energy security, and their cost is often prohibitive, leading commercial customers to weigh the cost of business downtime against the cost of installing on-site back-up power sources.

Schools could do the same if they had a way to go about it. Considering general levels of energy security and their rough costs is a good place to start. The following discussion outlines these basic considerations. Using this information, Appendix C, Part 2 provides a step-by-step method of determining the need for uninterruptible electricity for a particular school and the best means to provide it. Such simple and generic guidelines can be used for basic assessment purposes to start the process. Typically, school energy and facility managers have the experience and expertise to conduct the more detailed analysis required to weigh specific options, or local consultants and professional engineers are available to provide it.

Is Solar Secure Power Affordable?

The basic parameters of solar-extended back-up power economics are the cost of energy storage and related equipment and the avoided cost of shutting down a school when grid electricity service is lost. First, in considering the affordability of solar secure power, other potentially more economical ways of providing uninterruptible energy, including emergency generators fueled by dedicated and uninterrupted sources of natural gas, should be considered. Second, levels of emergency energy security should be identified, which depend on choices made by school boards based on local conditions, state policies, and economic considerations. To simplify the matter, multiple levels of targeted operational continuity security can be identified. The maximum level provides for full operation of the school based on a dedicated uninterruptible source. The minimum level provides for use of the school as a population shelter in emergencies based on a dedicated uninterruptible source capable of powering critical loads only. Other levels can be specified between these two extremes.

The average daily electricity production of a school-based solar power system can be determined by dividing its average annual electricity production by 365. Assuming the solar power system is sized to supply most of the school’s average net electricity consumption, a battery system should be sized to store a minimum of 50% of the full average daily DC output of the solar power array. UPS costs vary widely depending on their size and functionality, but battery capacity is a primary cost driver. For generic analysis purposes, the cost of battery energy storage for coupling with large rooftop solar power systems is assumed to be approximately $200/kWh. Using these simplifying assumptions, Table 5 summarizes strategies and options for ensuring various levels of operational continuity as well as the rough per pupil cost of implementing these options.

Table 5. Strategy, Options, and Costs of Operational Continuity

Operational Continuity Security Level	Strategy	Options	Cost (per pupil)
Unlimited Full	Unlimited uninterruptible power	Emergency generator (> 25 kW) fueled by uninterruptible natural gas	$50-100
		Energy storage (> 25 kW) with solar recharge capability	$50-100
Limited Full	Emergency power limited by fuel availability or battery capacity	Emergency generator (> 25 kW) fueled by interruptible natural gas or diesel fuel	$25-50
		Energy storage (> 25 kW) with limited solar recharge capability	< $50
Unlimited Partial	Unlimited emergency power for critical loads	Emergency generator (< 25 kW) fueled by uninterruptible natural gas	< $50
		Energy storage (< 25 kW) with solar recharge capability	$15-25
Limited Partial	Emergency power for critical loads limited by fuel availability or battery capacity	Emergency generator (< 25 kW) fueled by interruptible natural gas or diesel fuel	$15-25
Assumptions: *Solar power system output = 1,600 kWh/kW* *Installed battery cost = $200/kWh* *10-kW and 100-kW emergency generators @ $300-$1,000/kW depending on size, fuel, and fuel storage*			

Per pupil costs in Table 5 can be compared with per pupil benefits. Commercial businesses typically know or can easily calculate what the cost of a lost day of operation is and invest in on-site back-up power according to its cost in relation to revenue loss potential. Schools do not lose revenue when they shut down, but disruption in their operation adversely affects the local economy and may expose local and state education departments to unbudgeted costs. The school's daily operating cost provides an indicator, if not an accurate measure, of the overall economic impact of extended, unplanned school shutdowns. Per pupil spending in the United States averaged $8,019 per student in the 2002/2003 school year and varied from less than $5,000 to more than $13,000.[15] The number of legally mandated class days in a school year is assumed to be around 180.

Using these simplifying assumptions, Table 6 compares the cost of solar extended back-up power with the order of magnitude economic impact of school shutdowns using per pupil cost as a surrogate cost. A key factor in such crude analysis is the value of operational continuity.

Table 6 suggests a favorable benefit/cost ratio for scenarios involving more than one power-loss-related school shutdown per decade. Experience in Maryland, Florida, and other states suggests that shutdowns of the nature experienced in connection with major weather events may happen multiple times in a decade and last days or even weeks; the conservatism involved in assuming an average 1-day shutdown may offset the lack of conservatism involved in assuming an economic impact equal to the cost of a day of educational operations. For decision-making purposes, the analysis illustrated in Table 6 should be applied using case-specific information rather than national averages and nominal costs.

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[15] Richmond, E. (March 18, 2005). "Nevada 47th in Per-Pupil Funding." *Las Vegas Sun*.

Table 6. Benefits and Costs of Full Uninterruptible Back-up Power for Schools

Outage-Related Shutdowns per Decade (1)	Daily Per Pupil Cost of Educational Operations (2)	Per Pupil Unlimited Full Uninterruptible Power Cost (3)	Benefit/Cost Ratio
1	$60	$75	0.8
3	$60	$75	2.4
10	$60	$75	8

Notes:
1. Average 1-day shutdown duration.
2. Mean U.S. per per pupil spending; value of operational continuity assumed equal to cost of operation.
3. Mean of full uninterruptible power cost range from Table 5.

Policy: Will U.S. Schools be Energy Secure?

This is a question that will be decided by school boards and college and university administrators, public and private, state and local. Federal, state, and local emergency management organizations and their private partners (e.g., the American Red Cross) also have a major stake in the outcome, but at present they have no direct input to the design and energy management of the schools they rely on when disaster strikes.

There are no insurmountable technical obstacles to creating a national network of energy secure schools even now, and important enabling technologies (e.g., HEVs) are becoming available. The opportunity to save money while improving energy security is already being exploited in some significant cases. This opportunity clearly will expand as the cost of fuels and grid electricity increases and solar power costs continue to drop.

The most natural response to the opportunity is not available. Utilities operating local grids in the United States do not, for a variety of valid business reasons, invest in energy supply facilities on customer premises, even when their regulators permit or encourage such investment. An alternative solution that exploits tax-exempt public financing mechanisms is needed.

Fortunately, a promising solution is emerging. In certain states, and even nationally, there is sufficient solar power market activity to attract new ventures focused on providing "solar service," which includes financing. This means that a school district, having identified solar power as an element of its energy security strategy, could have the benefit of solar secure schools without diverting scarce capital budgets for the purpose. The San Diego Unified School District in California is doing just that. Working with Los Angeles-based Solar Integrated Technologies, the district is re-roofing 15 schools and three administrative buildings with roof-integrated solar power panels. Solar Integrated Technologies will install 1 million square feet of solar power arrays and maintain them at no cost to the district for 20 years. Leveraging state solar power rebates, the firm will sell the energy these roofs produce to the district at about half the cost now paid to San Diego Gas & Electric. The district anticipates $6.9 million in total cost savings over 20 years.[16]

School districts able to allocate capital to capture operating cost savings will be able to maximize electricity cost savings by self-financing their solar power needs, especially in states that adopt preferential "feed-in" tariffs that guarantee long-term purchase prices for solar electricity fed into the grid. Such long-term solar electricity purchase arrangements greatly facilitate access to low-interest private financing of solar power systems and are, therefore, already widely employed in European countries.

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[16] Louv, R. (March 22, 2005). "Solar Schools Help Shape Our Future." *San Diego Union-Tribune*.

Recommended Strategy for Solar Secure Schools

How can the most U.S. schools become energy secure as soon as possible? First, decision makers in the educational community must understand energy security issues well enough to make good decisions. Accordingly, the information summarized in this report and elsewhere has been used to create a simple step-by-step process that school officials can use routinely to assess their energy security options (Appendix C). Second, this process must be actively disseminated, e.g., by the U.S. Department of Energy and NREL.

Third, product-engineering gaps must be filled and new, more conveniently usable and cost-effective technologies brought into play. The importance of energy secure schools to public safety and education costs justifies creating a technology roadmap that addresses technology gaps and opportunities and focuses industry attention on product and market needs. The U.S. Department of Energy has spearheaded development of technology roadmaps in recent years; a small, focused effort of this sort should target solar secure schools.

Finally, policies tend to reflect business as usual. Energy secure schools are a future need, not a current reality. Modest adjustments in current policy are required and should be considered:

- How can consideration of cost-effective measures to increase the energy security of schools be encouraged?
- How can existing solar power incentive programs encourage upgrades of solar power systems to provide operational continuity during extended grid outages?
- What new approaches are needed to attract low-cost capital to school-based solar power system financing?

Energy secure schools need policy champions at the state level. Multiple national organizations (e.g., organizations of school administrators and school board members) could take the lead in the policy arena.

Appendix A: Energy Secure Schools—Technology, Economic, and Policy Considerations (previous work under NREL subcontract AEI-4-44238-01)

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ABSTRACT

School-based solar electricity systems can be upgraded to deliver emergency power when the grid is down for extended periods. Other emergency generation solutions (e.g., fuel-based emergency generators or grid-charged energy storage) have costs in the same range and are limited by their fuel or electricity storage capacity, among other drawbacks. In 2004, the U.S. Department of Energy's National Renewable Energy Laboratory initiated a project to develop guidelines and design specifications for low-cost, prepackaged photovoltaic (PV) systems on schools to enable the schools to be used as community emergency centers. Results to date are presented, including the following:

- Current practice and relevant federal, state, and other criteria, standards, and guidelines pertaining to the use of schools as community emergency centers
- Experience with school-based shelter operations and power needs during recent disasters and implications for PV system sizing and configuration
- Relevant deployment scenarios, design concepts, and costs.

1. INTRODUCTION

Over the next few years there will be a proliferation of grid-connected photovoltaic (PV) systems installed in schools across the United States. This trend has already started; 800 school-based PV systems will be operating by 2006, including large rooftop arrays made economically attractive by combining state clean energy rebates with other incentives. Continued deployment will be driven by the fact that schools operate during daytime hours when solar electricity is produced and also by projected PV cost reductions, escalating fuel and grid electricity costs, and steps to curtail greenhouse gas production and educate children regarding responsible energy use. This creates an unprecedented opportunity to make the nation's schools energy secure and suitable for use as community emergency centers.

2. SCHOOL-BASED EMERGENCY CENTERS

Disasters happen. Among other consequences, they disrupt grid power for extended periods. Meanwhile, our society relies increasingly on grid electricity for health, safety, and convenience. Extended loss of grid power over a wide geographic area threatens public health and safety. Vulnerabilities increase as populations age, building automation becomes more prevalent, and grid-powered medical treatments (e.g., dialysis) are more widely applied.

Power reliability measures (e.g., emergency generators and uninterruptible power supplies) are sized and configured to avoid loss of critical functions during power interruptions of less than a second to a few hours. However, when disaster strikes, grid power can be disrupted for much longer periods. Table 1 provides examples from the recent hurricane season in Florida. According to the American Red Cross, 21 of 50 states are vulnerable to similar hurricane-related consequences. Grid outages continuing after stored fuel and electricity run out can transform a modern building from a marvel of integrated operation into a threat to health and safety.

TABLE 1. 2004 HURRICANE-RELATED CASES AND CONSEQUENCES IN FLORIDA[1]

Case	**Consequences**
Hurricane Frances – Florida Statewide	200,000 people spent Saturday night in 407 evacuation shelters
Hurricane Frances – Palm Beach County Schools	$300,000 loss of fresh and frozen food
Hurricane Frances – Flagler County Schools	Two of three school-based general shelters without power
Hurricane Jeanne – Polk County	73 of 122 schools without electricity; 2-3 weeks of classes cancelled
Hurricane Charley – Charlotte County	Power outages of up to 2 weeks; schools closed for 4 weeks; power outage affected gas stations, impacting portable generator fuel supply
Hurricane Frances and Jeanne – St. Lucie County	14 shelters with emergency generators with 3-day fuel capacity; all were used for both hurricanes for as long as 3 weeks; some had no grid power for 7 days; some emergency generators failed
Hurricanes Frances and Jeanne – Pinellas County	Power outages of up to 1 week; Port of Tampa closed, creating major fuel supply problem

To provide emergency shelter, a building must have power for its security and communication systems, emergency lighting, medical equipment, food storage, ventilation, and even heating and cooling during weather extremes. Accordingly, buildings used in emergencies should be "energy secure," i.e., they should have reliable power for at least some of their internal systems. They need it during normal operations, but the need becomes critical when disaster strikes. The longer the period of emergency operation, the more critical the need for emergency power becomes.

School buildings are the primary local emergency shelter option for people ordered or choosing to evacuate "at risk" areas. Schools are also used to shelter evacuees from buildings that have become uninhabitable due to grid outages. In its *Design Guide for Improving School Safety in Earthquakes, Floods and High Winds*, the Federal Emergency Management Agency simply states that "schools intended for use as shelters and/or emergency response after a (wind) storm should be equipped with an emergency generator."[1]

3. UNMET NEED FOR ENERGY SECURE SCHOOLS

A case could be made that all schools should be energy secure. However, most schools are not. Even those used as evacuation shelters typically are not. Emergency generators are not an ideal solution; they require expert maintenance and operation to remain reliable. They are noisy, aggravating the trauma of disaster refugees, and provisions for long-term fuel storage raise additional environmental and safety concerns. Though recommended, they are legally and technically optional in most cases. Other cheaper but less reliable strategies are used, e.g., planning to bus evacuees to shelters still receiving grid power or equipping some schools for connection to a portable generator that may be delivered by relief organizations.

4. PV-POWERED SCHOOLS

Exploiting PV-powered schools is a better solution in many cases. Public schools are a natural application for on-grid solar electricity. They draw electricity from the grid mostly during daylight hours when electricity prices rise to $0.20/kWh and higher. They typically have ample unused roof space that can be covered with solar arrays, and the insulating effect of the arrays can reduce heat gain through the roof, thereby reducing electricity use for space conditioning. Schools are built to last, having typical operating lifetimes of 50–100 years. Further, school property is not taxed. Thus, a capital item such as a solar power system can be financed over decades based on the proceeds of low-yield, tax-free bonds. Finally, the operating cost of a solar power system is minimal and does not vary from year to year. Its output reduces grid power costs that escalate and are subject to uncontrolled upward spikes that can impact educational program budgets.

Within 5 years, school-based PV systems will be cost-effective, even without incentives, across a broad range of southern U.S. states and will be especially cost-effective in the Sun Belt and states offering incentives for solar electricity. Table 2 summarizes the current outlook for cost-effective school-based PV systems, specifically:

- **Large school-based solar electricity systems** are more cost-effective than smaller ones and have installed costs (in 2005) that are marginally cost-effective without incentives in areas having excellent solar resources, i.e., the true Sun Belt areas of the U.S. southwest. They will have similar economics across a broad swath of southern states in 2010 based on expected cost reductions.
- **Smaller school-based solar electricity systems** may be deployed where larger systems are still uneconomic; they will pay back part of their initial cost during their economic life. Cost subsidies like those offered in California and New Jersey may be required to encourage their consideration.

TABLE 2. NET KWH COSTS FOR SCHOOL- BASED PV

Poor Resource - 20 kW systems - 2005 (6)	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Cost - $/kWh (2)(3)	0.4	0.4	0.4	0.4	0.4	0.4
Avoided Cost - $/kWh (4)	0.10	0.12	0.13	0.16	0.18	0.21
Net Cost - $/kWh (1)	**0.30**	**0.28**	**0.27**	**0.24**	**0.22**	**0.19**
Excellent Resource - 200 kW system - 2005 (5)						
Cost - $/kWh (2)(3)	0.15	0.15	0.15	0.15	0.15	0.15
Avoided Cost - $/kWh (4)	0.10	0.12	0.13	0.16	0.18	0.21
Net Cost - $/kWh (1)	**0.05**	**0.03**	**0.02**	**-0.01**	**-0.03**	**-0.06**
Good Resource - 200 kW system - 2010 (5)						
Cost - $/kWh (2)(3)		0.15	0.15	0.15	0.15	0.15
Avoided Cost - $/kWh (4)		0.12	0.13	0.16	0.18	0.21
Net Cost - $/kWh (1)		**0.03**	**0.02**	**-0.01**	**-0.03**	**-0.06**

Notes:
1. All costs in 2005$.
2. Public bond financing, no incentives, annual capital charge rate = 5%.
3. Poor, good, and excellent resources: 1,000, 1,500, and 2,000 kWh/kW.
4. Real grid electricity annual cost escalation = 3%.
5. Single 200-kW system at $6,000/kW installed in 2005 and $4,500/kW installed in 2010.
6. Ten identical packaged 20-kW systems at $8,000/kW installed in 2005.

Although sustainable or “green” design is an emerging standard for new school construction, marginal cost-effectiveness is typically not a sufficient condition for investments in solar energy systems. Capital budgets for public schools must be approved directly by local voters, making it problematic to set aside a portion of such funds for discretionary energy-related investments whose costs are recaptured over decades, not years.

So, in spite of the economic factors cited above favoring solar electricity systems on schools, actual deployment in the near term likely will depend on the availability of appropriate economic incentives and other policies that differentiate or decouple energy infrastructure investments from educational infrastructure investments. Policies are needed that avoid forcing school boards to choose between low and stable lifecycle energy costs and near-term school construction and renovation needs.

This is easier said than done. The most natural solution is not available. Utilities operating local grids in the United States do not, for a variety of valid business reasons, invest in energy supply facilities on customer premises, even when their regulators permit or encourage such investment. An alternative solution is needed that exploits tax-exempt public financing mechanisms.

5. DISASTERS AND BACK-UP POWER

There is no shortage of information and guidance related to preparing for disasters and emergencies. Given the many life-and-death issues confronting emergency managers and responders, most publications give scant attention to the issue of power continuity and typically provide no guidance regarding the equipment involved or strategies for its installation and operation. On the other hand, emergency management personnel consistently say that, during an actual emergency, lack of back-up power adversely affects important aspects of emergency and sheltering operations. For example, local emergency managers point out the following occurrences during disaster conditions:

- **Portable generator** availability is typically limited and subject to competing demands; available portable generators are dispatched to disaster-stricken areas to serve the highest public safety needs, which may not include mass care. Also, the resources needed to ensure proper, safe hook-up may not come with the portable generator.
- **Permanent fuel-based generators** rely on stored fuel or sources of fuel that are often compromised by the event that created the emergency. For example, weather disasters can result in extended disruption of gasoline and diesel fuel deliveries, and natural gas infrastructure may be shut down for public safety reasons in the aftermath of earthquakes. Fuel-based generators require routine maintenance, and their noisy operation adds to the stress of nearby human populations coping with the trauma of the disaster.
- **Battery-based uninterruptible power systems (UPS)** typically have sufficient capacity to carry over critical loads for one to several hours, after which the loads must be switched over to other back-up power sources. Evacuation shelters, by contrast, often remain in operation for several days or even a week or longer. For this reason and for other operational considerations, UPS are less likely than generators to be the choice for facility-wide back-up power.

6. MAKING PV-POWERED SCHOOLS ENERGY SECURE

In relation to the abovementioned range of current options, a UPS capable of being recharged by a PV array has major benefits. Instead of a battery bank charged from the grid and useful only as long as its charge lasts, stored energy is replenished daily and can be drawn on until grid power is restored. Historically, solar/battery hybrids have been the preferred solution for applications requiring highly reliable power independent of the grid, including some for which the grid is close by but less cost-effective.[2]

Battery bank sizing for PV-powered energy secure schools will consider critical loads and energy consumption during mass care operations as well as collateral applications, such as the following:

- **Powering resumption of educational operations.** In the wake of hurricanes and other disasters, large areas are without power, sometimes for weeks. Schools remain closed even after evacuees leave. PV-charged UPS would permit more timely resumption of classes and school activities than would otherwise be possible in these cases.
- **Mitigating black-out and brown-out impacts.** When the local grid is overloaded, grid operators disconnect loads and/or reduce system voltage to limit power flows. The availability of stored energy connected to the local grid that could be dispatched during such conditions would be valuable to the utility and the community it serves.[3]
- **Avoiding unplanned school evacuations and shutdowns.** Depending on UPS capability, the need to evacuate or shut down a school when grid power is lost could be avoided. For example, at least three severe weather events, including ice storms, severe thunderstorms, and hurricane-related winds, have occurred in the Washington, D.C., suburbs in the past several years. These resulted in large swaths of urban and suburban areas being without power for 2–3 days or more while utility crews from out of state helped restore downed power lines. Montgomery County (Maryland) schools have emergency generators for use in such emergencies, but most schools in most other parts of the United States do not. Under similar conditions they must shut down and await restoration of grid power.

7. ENERGY SECURE SCHOOL DEPLOYMENT SCENARIOS, DESIGN CONCEPTS, AND COSTS

A number of design goals are possible for the basic PV installation. Their feasibility depends on the following:

- Type of project (new school or renovation)
- Availability and limitations on incentives
- Grid electricity costs and reliability
- Building load profiles and energy use
- Local solar industry competencies.

A number of design goals are also possible for adding solar-enhanced back-up power capability; generally, the goal should be to take full advantage of the battery-replenishment capability of the PV array. The feasibility of such goals depends on the following:

- Whether the school qualifies or will be upgraded to qualify for mass care uses
- Type and capability of existing back-up power provisions
- Power demand of equipment used during extended emergencies.

Beyond these considerations, loads to be served in extended emergencies only can be identified generically based on expected minimum and nominal daily emergency power generation. Operational strategies and procedures for limiting demand to the highest priority daily needs should be developed in advance. Regarding sizing, there are three basic scenarios to consider:

- **Where solar electricity is already cost-effective.** Where solar electricity is cost-effective for school rooftop applications, the regional and local solar industry will likely have acquired appropriate experience. Schools will be equipped with the largest possible solar array, which, based on the roof area of typical public elementary and high schools will have a peak output in the 150–500 kW range. For example, two schools in northern New Jersey are being equipped with 180- and 360-kW systems. Figure 1 shows a portion of the smaller installed array. In such cases, battery storage ideally will be sized relative to the capability of the array to keep it charged during periods when it is the school's only power source.

Figure 1. Rooftop PV array on Bayonne, NJ high school

- **Where solar electricity system sizes are limited by available incentive funds.** Where the economic feasibility of solar electricity depends on limited pools of public funding, smaller PV arrays may be deployed in sizes of 10–30 kW, or roughly 10% of the fully cost-effective range above. For example, approximately 30 schools in California are being equipped with systems in the 20–30 kW range.[4] In such cases, battery storage can be sized according to the requirements of specific loads that must be carried for a school to function as a special needs shelter in an emergency, i.e., loads related to the safety and medical care of elderly or disabled people evacuated from homes, assisted living facilities, nursing homes, or hospitals.

- **Where solar electricity systems have been installed for educational or public relations purposes and are too small (i.e., < 5 kW) to power a full range of critical loads.** For example, more than 500 schools in the United States are hosting PV systems in the 1–5 kW range that are being paid for by local utilities or state clean energy funds for purposes of increasing awareness of renewable energy or to enhance the public's perception of the donor. Typically, these systems are configured to feed small amounts of electricity directly into the local grid, essentially bypassing school building circuits. These installations represent an opportunity to enhance the school's operational capabilities during power outages by, for example, using them to power battery-charging stations for emergency lighting, computer systems, and other UPS batteries that are discharged in the early hours of an extended grid outage.

Design concepts responsive to the above scenarios and to the other considerations mentioned are summarized parametrically in Table 3. They should be considered in reference to the cost of other solutions. An alternative to upgrading an existing or new solar electricity system to serve critical loads in an emergency is to install a diesel generator. The average retail cost of an emergency generator rated between 10–100 kW is around $400–$700 per kW, but this does not include long-term fuel storage, automatic electrical interface equipment, or installation and commissioning.[5] Portable emergency generators with limited onboard fuel storage are available at retail for as little as a few hundred dollars per kW. Permanent installations that include industrial-quality generators, 3 or more days worth of fuel storage, and provisions for automatic power transfer typically cost several hundred to more than a thousand dollars per kW depending on their size. The most economical size is a few hundred kW; smaller and larger installations cost more.

Table 3 puts the cost of upgrading a school-based PV system in perspective as follows:

- The cost of secure energy from an existing PV installation (i.e. < $1,500/kW) can be in the same range as the cost of secure energy from permanent fuel-based emergency generators having adequate fuel storage to remain in operation for more than a few days.
- A PV system reliability upgrade will be more cost-effective in powering specific critical loads essentially indefinitely. It will be significantly less cost-effective where the requirement is to power all loads, both critical and non-critical, for only a few hours.

Thus, the worst-case duration of the expected emergency and its effect on fuel supply may be decisive factors. Disasters that affect large areas and involve extended recovery operations can disrupt fuel supplies, thereby rendering fuel-based emergency generators ineffective after their onboard storage is depleted.

TABLE 3. DEPLOYMENT SCENARIOS, DESIGN CONCEPTS, AND COSTS FOR PERMANENT INSTALLATIONS

Rooftop PV System					**Reliability Upgrade**					**Cost Summary (4)**		
PV Array			**Inverter**		**Battery Storage**			**Power Conv.**				
Peak Output (kW)	Area (square meters)	Installed Cost ($K)	Grid-connect	Installed Cost ($K)	Peak Output (kW)	Energy Storage (kWh)	Installed Cost ($K)	Inverter	Installed Cost ($K)	Energy ($K)	Secure Energy ($K)	**Total ($K)**
200	2,000	1,050	Grid feed-in inverter	150	125	1,000	238	UPS (1)	40	1,200	278	**1,478**
20	200	113	Grid feed-in inverter	20	12.5	100	24	Dual mode (2)	6	133	30	**162**
5	50	31	Dual-mode inverter	6	5	25	7	N/A (3)	0	38	7	**44**

Notes:
1. Off-line standby UPS product, new or refurbished, either part of original installation or retrofit.
2. Inverter retrofit - cost of the original inverter credited against the cost of a dual-mode replacement.
3. Assume dual-mode inverter is part of original installation.
4. Based on typical current costs of included subsystems.

8. STEPS TOWARD A NATIONAL NETWORK OF ENERGY SECURE SCHOOLS

Several steps should be taken to ensure that solar electricity is used to best effect in support of U.S. public schools and their collateral use as mass care centers in disaster situations:

- **Standards.** PV/battery hybrid emergency power options should be addressed in standards and selection criteria for crisis and mass care centers.
- **Technical Demonstrations.** Procurement guidelines and technical specifications are also needed, as well as demonstration projects to validate them; options for upgrading school-based PV systems for emergency power purposes must be demonstrated so that proper comparisons with existing solutions can be made by school officials and emergency managers.
- **Decision Tools.** School boards, school designers, and school business managers need guidelines and quantitative information to help decide if solar electricity is the right choice and to maximize its functional and economic benefits. A strategy and resource guide for this purpose should be developed and disseminated.
- **Incentives.** Separate measures are needed to encourage school-based PV systems and related reliability upgrades, e.g., loans that can be repaid by school boards based on avoided grid power purchases. Incentives should also be provided to schools investing in solar to encourage consideration of reliability upgrades, e.g., where a state clean energy fund is offering rebates for a portion of the initial cost of a PV system, the state and the Federal Emergency Management Agency (FEMA) could collaborate to provide a similar rebate for a reliability upgrade.[7]
- **R&D.** Until now, there has been little demand for large battery-coupled PV systems for grid-connected buildings. Relevant battery and power conversion technology is widely used in other commercial applications; however, vendors typically have little or no experience with solar electricity applications of their products. A collaborative R&D initiative would be an appropriate response to the need for sustained industry attention.
- **Awareness.** There is a need for greater awareness of the role solar electricity will play in the future energy mix and especially of the opportunity to exploit its collateral potential as an emergency power source. Outreach to the public education and emergency management communities could be based on a model Energy Secure Schools program in a specific state coordinated among emergency management, education, and energy agencies as well as the American Red Cross. Relevant federal agencies should consider offering planning grants to encourage development and implementation of such a model program.

9. COUNTING THE COSTS

It is possible to roughly estimate the scope and cost of a national network of energy secure schools.[8] It would involve the deployment of 2,000–3,000 MW of solar electricity systems on approximately 20,000 schools at a cost of $10–$15 billion over 10 years. In the context of current industry capability, this is ambitious but feasible: global PV equipment shipments are nearly 1,000 MW per year and growing at 30% annually.

Eighty percent of this cost is attributable to energy production that offsets purchases from the grid; even without incentives, it will be recovered via avoided grid electricity purchases over 10–20 years, depending on the average annual rate of grid electricity price escalation. The remaining 20% ($2–$3 billion) would be the public cost of energy secure public crisis centers. It must be weighed against lifesaving and mass care benefits as well as the value of buffering the effects of grid outages during normal school operations.

10. ACKNOWLEDGEMENTS

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11. REFERENCES

[1] From various sources including personal face-to-face interviews with local emergency management and school officials in Florida counties affected by three 2004 hurricanes, including Charlotte, Pinellas, Polk, and St. Lucie.

[2] Federal Emergency Management Agency. *FEMA 424: Design Guide for Improving School*

Safety in Earthquakes, Floods, and High Winds. January 2004.

[3] Varadi, P.; Braun, G. “Security PV.” *Renewable Energy World*; September–October 2003.

[4] Perez, R.; Collins, B. “Solar Energy Security.” *Refocus*; July/August 2004; p. 24–26.

[5] California Energy Commission. *Solar Schools Program*. www.consumerenergycenter.org/solar_schools/program.html

[6] Fraser, H.; Johnson, J. *Standby Electric Generators for Emergency Farm Use.* Ontario Ministry of Agriculture, Food and Rural Affairs; May 1999; www.gov.on.ca/OMAFRA/english/engineer/facts/99-005.htm.

[7] Whereas most U.S. PV incentives are indexed to array output, legislatures abroad (e.g., in Germany) are considering incentives for PV-coupled energy storage.

[8] A national system of PV-powered public crisis centers was proposed by the U.S. Department of Energy in 2002. See Plympton, P.; Thornton J. "Solar Schools as Community Emergency Centers." *SOLAR 2002*; Reno, NV; June 15–20, 2002. The current scope and cost are consistent with the U.S. Department of Energy’s original estimate.

Appendix B: Plug-In Hybrid School Buses for Future Solar Secure Schools

Plug-in HEVs are hybrid cars with enhanced battery capacity. As the term suggests, plug-in HEVs—which look and perform much like "regular" cars—can be plugged in to a 120-volt outlet (e.g., each night at home or during the workday at a parking garage) and “fueled” from electricity sources, including the local grid or a rooftop solar power system. Plug-in HEVs are thus able to run on stored electricity for much of a typical day's driving, up to 60 miles per charge depending on the size of the battery, which is far beyond the average U.S. commute. When the charge is used up, the vehicle automatically switches to running on the fuel in its fuel tank. A plug-in HEV with a 60-mile range operating on battery power would have a battery capacity of 15–30 kWh depending on its category; the high end of the range would correspond to a heavy vehicle such as an SUV.

Plug-in HEVs operating on grid power stored in onboard batteries would have equivalent fuel costs well under $1/gallon and an emissions profile roughly half that of a conventionally fueled vehicle. Electric utilities are interested in promoting plug-in HEVs for purposes of revenue enhancement, local pollution mitigation, and the potential to use the combined storage capacity of numerous plugged-in HEVs to store cheap off-peak energy for potential use in meeting system peaks. Preliminary thinking regarding deployment suggests an initial stage involving fleet vehicles operated by local governments and school districts.[17]

A school district’s school bus fleet would be an appropriate application for plug-in HEVs. The buses are operated during daytime hours over a limited range and could be “refueled” at night with low-cost, off-peak electricity from the local grid and from roof-mounted solar power modules. Based on the dimensions of a typical school bus, the roof-integrated solar power system would have a peak capacity of 1–2 kW and would be capable of delivering an average of 5–10 kWh to a hybrid bus battery daily.

It makes sense to integrate current thinking about plug-in HEVs and energy secure schools. Doing so suggests a scenario involving the use of plug-in hybrid school buses in combination with school-based solar power systems to keep the schools operating during extended grid outages. It is even imaginable that the plug-in HEVs could be “fueled” by the school-based solar power systems and also provide limited capability to avoid purchases of grid electricity during high-cost peak-demand periods.

Further study and, more importantly, experience will be required to determine how schools can exploit the combination of solar power and plug-in HEVs to cut operating costs. It is beyond the scope of this report to predict the rate or pattern of adoption of HEVs in the United States, but even modest adoption rates could easily keep pace with the parallel deployment of solar power systems. For example, with a battery capacity of 50 kWh each, 10 plug-in hybrid school buses could be refueled using a 100-kW school-based solar power system producing a daily average of 500 kWh. This daily average is typical of U.S. Sun Belt states.

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[17] Duncan, R. (February 16, 2005). “Gas-Optional Vehicles (Plug-In Hybrids).” Austin Energy. Informal presentation to ACORE.

Appendix C: Should Our Schools Be Energy Secure? A Guide for Decision Makers

Purpose

Strategic questions of school energy security must be answered by school boards and school administrators. School boards typically do not concern themselves with energy matters, so they need a simple methodology for answering the questions.

As discussed above, costs of U.S. electric service vary significantly from location to location and are subject to varying volatility based on generation mix, economic regulation, and so forth. Reliability of electric service is subject to even greater variation, and the diverse approaches to deregulation among the states may lead to even greater variation in the future. Meanwhile, local and regional grids differ significantly in terms of the disasters to which they are vulnerable and in the economic capacity of local and regional grid operators to pay for the levels of redundancy, equipment capacity margins, and preventive maintenance that were accepted standards across the U.S. industry in former times.

Because energy security has two dimensions—cost stabilization and emergency preparation—the methodology must address both. Part 1 of the following guidelines is intended to help define a strategy to stabilize energy costs. Part 2 is intended to help create a strategy to avoid operational disruption and unsafe conditions. The method used in both cases recognizes the lack of credible future forecasts and uses available historical information to quantify relevant trends.

Analysis

Part 1: Energy Cost Stabilization

Background

Investigation of the economic costs and benefits of school-based solar power systems in the United States leads to the following conclusions:

- Large school-based solar electricity systems have installed costs such that they are now (in 2005) marginally cost-effective without incentives only in areas having excellent solar resources (i.e., the true Sun Belt areas of the U.S. southwest) and will have similar economics across a broad swath of southern states by 2010, based on expected cost reductions.
- Smaller school-based solar electricity systems that may be deployed where larger systems are still uneconomic will only pay back part of their initial cost during their economic life, so cost subsidies in the range currently offered in California and New Jersey may be required to encourage their consideration.

Electricity prices in recent years have become more volatile with a strong upward trend. The more important factor is volatility. Costs that can be reasonably forecasted are manageable. Big energy cost surprises can cause serious problems. Every school district knows its annual operating cost and the portion of it that relates to its electricity use. Some districts and schools are able to pay special attention to controlling energy costs, but it is not realistic to suggest that a school district undertake complicated economic analysis to determine if solar power makes economic sense. A simpler step-by-step approach is as follows:

Step 1: Determine current electricity costs. Average grid electricity prices paid by schools are \$0.05–\$0.15 per kWh and can be computed by simply dividing a school's annual electricity bill by its annual electricity use in kWh. If the price is close to or above \$0.10/kWh, go to Step 2.

Step 2: Determine the scale of future electricity price increases. Using historical price information, an electric price "volatility index" can be calculated simply by repeating Step 1 for each of the five previous years, determining the difference between highest and lowest average cost during the period, and dividing by the lowest cost. Table C-1 illustrates the calculation for selected states.

Table C-1. Historical Grid Electricity Costs, 1999–2003[18]

	California	Florida	Hawaii	Maryland	New Jersey	New York
Year	**Cents/kWh**					
1999	10.05	6.22	12.74	6.82	9.74	11.19
2000	10.25	6.25	14.81	6.55	9.14	12.65
2001	12.49	7.08	14.81	6.42	9.19	12.98
2002	13.22	6.64	14.11	6.09	8.87	12.46
2003	12.19	7.13	15.02	6.95	9.25	12.93
2004 (2)				9.04		
Mean	**11.64**	**6.66**	**14.30**	**7.01**	**9.24**	**12.44**
Range	3.17	0.91	2.28	2.95	0.55	1.74
Range - % of mean	27%	14%	16%	42%	6%	14%
Volatility index (1)	**5%**	**3%**	**3%**	**8%**	**1%**	**3%**

Notes:
1. The volatility index is calculated by determining the maximum, minimum, and average electricity prices for each of the preceding 5 years and dividing the difference between the maximum and minimum by five times the average. The index is a rough measure of the expected future annual percentage change.
2. 2004 Maryland prices are assumed to be 30% above 2003, based on published rate increase summaries by PEPCO.

Step 3: Determine a reference price for future grid electricity purchases. Calculate a nominal average grid electricity price for the next 10 years by multiplying the average current price from Step 1 using the following formula:

Average 10-year electricity price = current price x [1 + 2 x (volatility index)]

Step 4: Solicit competitive bids for solar power "service" (i.e., the equivalent of grid power service), monthly billing for electricity from solar power systems mounted on a school's roof but financed and operated by a private company. Companies offering such service can be identified by searching the web using key words such as "solar" and "finance." The bids will typically lock in a price for solar electricity 10–20 years into the future. From these bids, determine the best available solar electricity price (cost per kWh delivered) for the next 10 years.

Step 5: Evaluate the bids in relation to grid electricity prices. If the 10-year average solar electricity price is in the same range as the nominal 10-year average grid electricity price, contracting to purchase solar electricity is a prudent choice, especially if arrangements can be

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[18] Energy Information Administration, www.eia.doe.gov/cneaf/electricity/epa/average_price_state.xls.

made to extend the fixed-price solar electricity purchase period beyond 10 years or take over ownership of the solar electricity system at the end of the power contract period.

Step 6 (optional): Determine if self-financing of a solar power system would result in significant cost savings. Energy services companies are able to structure power project financing to take advantage of tax incentives and so forth, but public agencies such as school districts have the advantage of access to low-interest, long-term, tax-exempt debt financing ideally suited to low-risk capital projects having a relatively long economic life. If self-financing is feasible, it's advantages can be weighed by soliciting turnkey bids for nominal 300, 150, and 100 kW solar power systems, depending on the school's size (i.e., for high, middle, and elementary schools, respectively). Nominal sizes are provided here for scoping purposes. The recommended size for schools in a particular system or area is a matter of professional judgment based primarily on expected peak demand in normal operation and whether full operation of heating and cooling systems is critically important to educational operations. State energy offices and independent groups with knowledge of applicable programs, incentives, and restrictions should be called on for assistance in identifying potential bidders and preparing uncomplicated letter solicitations.

Part 2: Emergency Energy Security

Background

The affordability of energy secure schools is not a strictly economic question and cannot be answered with precision. There are two key factors in answering the question: safety and operational continuity. For ethical and liability reasons, the private sector has become much more attentive in recent years to providing a safe work environment for employees. Safety has become a top priority for many major corporations and is equally important for children and teachers. Recognizing the safety and operational continuity value of reliable electricity, some school systems equip their buildings with emergency generators. Although many do not, with more and more critical automated systems dependent on electricity, it is reasonable to expect full back-up power capability for schools to become the standard rather than the exception as it is now. How long it will take to reach a tipping point in this direction is unknown. Looking only at the direct economic cost to a school system of sending students home when the power goes out or closing schools until power is restored, the cost of emergency power may be difficult to justify. Calculating the indirect cost to the local economy of the ripple effect (both safety and economic) of a community reallocating its resources to care for children while its schools are unexpectedly closed, might give a different answer. For purposes of rough analysis, the cost of operating the school can be used as an indicator of the economic value of operating the school.

It is well known that the grid is interruptible. What is not well known is that grid power reliability varies substantially even within the same utility service area, i.e., some electricity customers experience frequent or extended outages and others do not. The substantial variation in grid reliability depends on technical factors typically invisible to a school district and its facility managers. These include the general age and condition of regional and local transmission and distribution infrastructure, funding and technical adequacy of related maintenance programs, circuit and equipment loadings, vulnerability to damage by accidents and storms, and, most significant and least understood, levels of redundancy and ability to switch loads from one substation or feeder to another. Typically, reliability "is what it is" unless the grid customer is willing to consider paying for equipment upgrades, redundant connections, or both. These options typically provide improved but not full energy security, and their cost is often prohibitive, leading commercial customers to weigh the cost of business downtime against the cost of installing on-site back-up power sources.

Schools could do the same if they had a way to go about it. Although schools and school districts typically lack the expertise to assess the impact of energy industry trends that may affect their vulnerability to future grid disruptions, their facilities staff will know how many grid disruptions have affected their operations in recent years and can apply this experience to assess the economic value of back-up power relative to its cost. The following simple step-by-step approach is suggested for first-stage analysis. Typically, school energy and facility managers have the experience and expertise to conduct the more detailed analysis required to weigh specific options, or local consultants and professional engineers are available to provide it.

Step 1: Test the school's vulnerability to grid outages. Determine the number of grid outages affecting the school in the most recent decade that required evacuating the school or rendered it unable to hold classes on a regularly scheduled school day. Estimate the number of days school operations were so affected.

Step 2: Compute the average daily cost of school operation by dividing the annual cost per student by the number of days of the legally mandated school year and multiplying by the number of students.

Step 3: Roughly estimate nominal economic value of back-up power over the next 10 years by multiplying the results of Step 1 and Step 2. If the result exceeds $30,000 for an elementary school, $50,000 for a middle school, or $100,000 for a high school, go to Step 4.

Step 4: If the school has natural gas service, check with the local natural gas utility to determine if it can guarantee an uninterruptible supply of natural gas for emergency power purposes and compensate the school district if the uninterruptible supply is not available when needed, i.e., during a grid outage.

Step 5: If the natural gas utility can guarantee uninterruptible service, request assistance from the utility in identifying sources of natural gas fueled emergency generators. Request quotes for installation and hook-up of appropriately sized generators: 100 kW for high schools, 50 kW for middle schools, and 30 kW for elementary schools.

Step 6: If the natural gas utility cannot guarantee uninterruptible service, and if the school is equipped with a rooftop solar power array, determine its average daily electricity production by dividing the solar power array's average annual DC electricity output by 365. A battery system should be sized to store a minimum of 50% of the full average daily DC output of the solar power array.

Step 7: If the solar power system's average daily production is less than the school's average daily energy use, determine the most critical circuits to remain energized during an extended grid outage, and request design/install bids for standard, grid-isolated UPS equipment, with battery storage capacity consistent with Step 6, provisions to charge it alternately from the grid or the solar power array, and peak output consistent with the nominal loadings of the selected circuits.

Step 8: If the school is not equipped with a solar power array, determine the maximum potential output of a solar power array that could be installed when economically feasible. Follow the guidelines in Step 7 in procuring and installing UPS equipment for interim use in supporting normal school operations to the extent possible during a limited grid outage of a day or less and for later integration with a solar power array.

Note: With any form of emergency generation, the option exists to configure it to adjust and optimize the school's pattern of grid electricity use, e.g., to draw electricity from the grid at favorable prices, minimize demand charges, take advantage of favorable rates utilities offer to customers willing to reduce use or be disconnected during high demand periods, and so forth. Consideration of such options is appropriate if solar power and/or emergency generation or major UPS equipment is installed or planned. However, the best options will be highly site and utility specific; involve specific costs, operational constraints, and maintenance requirements; and should in most cases be defined and evaluated with the assistance of properly qualified engineering consultants.[19]

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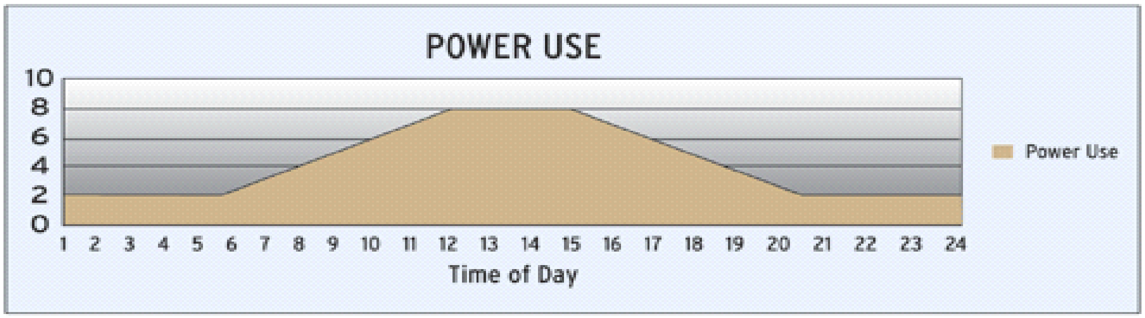
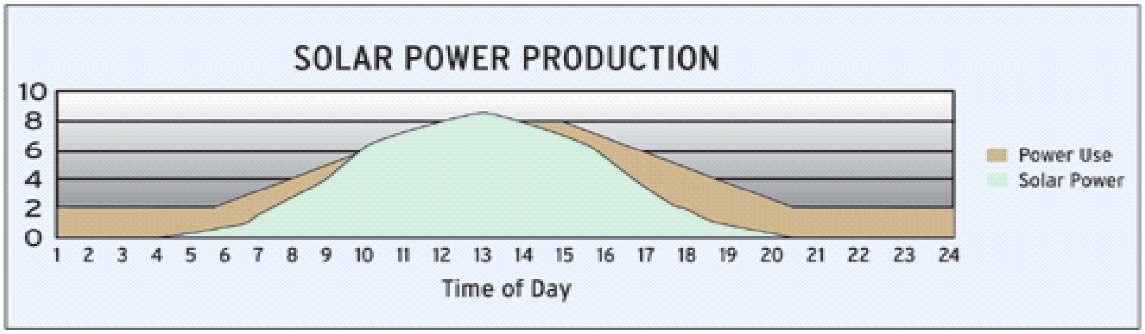
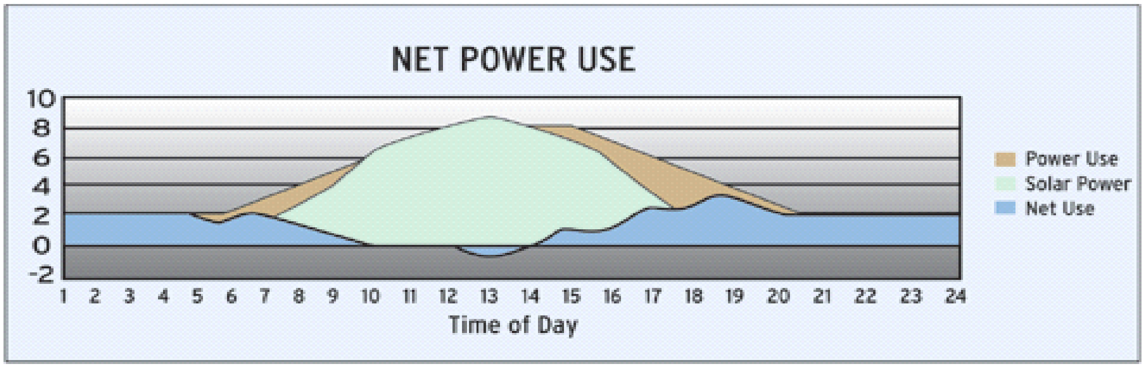
[19] For a discussion of related issues, see Audin, L. (February 2005). "Showcase: Power." *Building Operating Management*, www.facilitiesnet.com/bom/article.asp?id=2568.

Appendix D: Illustration of Load Leveling by a Commercial Rooftop Solar Power System[20]







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14. ABSTRACT *(Maximum 200 Words)*

Large numbers of solar power systems are being deployed at U.S. schools. Schools are used routinely in sheltering vulnerable populations during and after major disasters. An “energy secure school” would be protected against grid and natural gas supply disruptions, and a “solar secure school” would be insulated from significant unplanned increases in its annual energy bill. Solar secure schools are not only technically feasible but also economically justified when grid electricity prices are high and volatile or schools are shut down by grid power outages more than once every 10 years. Solar power prices and grid electricity prices are trending strongly in opposite directions, so solar secure schools soon will be an attractive cost control and public safety strategy in most states. The present effort has produced a simple step-by-step process that school officials can use to assess energy security options.

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solar; pv; photovoltaics; energy security; schools; plug-in hybrids

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