The Practical Implementation of Distributed Solar CHP With Thermal and EV Battery Storage for Schools

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Abstract

As much as five percent of energy consumption in a typical U.S. city comes from K-12 and higher education schools. Retrofitting these schools to be 100% renewable-heated and powered, with thermal and electric battery storage, can accelerate community clean energy. This is a concept plan for the implementation of 100% solar energy for a middle school with an approximate four megawatt electric and thermal load, with 4 million kW-hours/year energy, including school bus electric vehicle (EV) charging. An evaluation is provided for solar photovoltaics (PV), vehicle to grid (V2G), thermal and electric storage systems, including hot water, hot bricks, and stationary batteries. Distribution interconnection and infrastructure applications are considered. This paper is an extension of the author's paper "Accelerating 100% Renewable Energy Plans" (Smiley 2023).

Keywords: renewable energy for schools, accelerating renewable energy

1 Introduction

This is a "electrification" plan, increasing the present consumption of electricity 2.74 times for a school utilizing solar PV, thermal and electric storage, bus EV V2G (and other school vehicles) batteries with bi-directional infrastructure upgrades, policies, and smart grid controls. The goals of this plan include:

- Elimination of fossil greenhouse gases (GHG).
- Use of 100% renewable energy of > 4 million kW-hours/year.
- Expansion of solar PV site availability — installing 3,400 kWac of solar PV.
- Purchase and operation of electric V2G buses lowering operating costs while providing electric peak shaving capabilities.
- Installation of solar PV, electrical and thermal storage to cover both electric (37%) and thermal energy (63%) needs. See Figure 1 below.
- Distribution of municipal electricity increased by 2.74 times
- Decrease in overall energy costs to the school and public utility
- Connection into the distribution system substation with limited electric grid upgrades
- Elimination of interconnection delays, avoiding "Independent System Operator" (ISO) requirements and transmission upgrades
- Use of "high load-factor" electric rates, providing lower cost, off-peak electricity 80% of the time
- Use of electricity (mostly off-peak) at a price competitive with natural gas and much lower than petroleum for space, water heating, and vehicle fuels

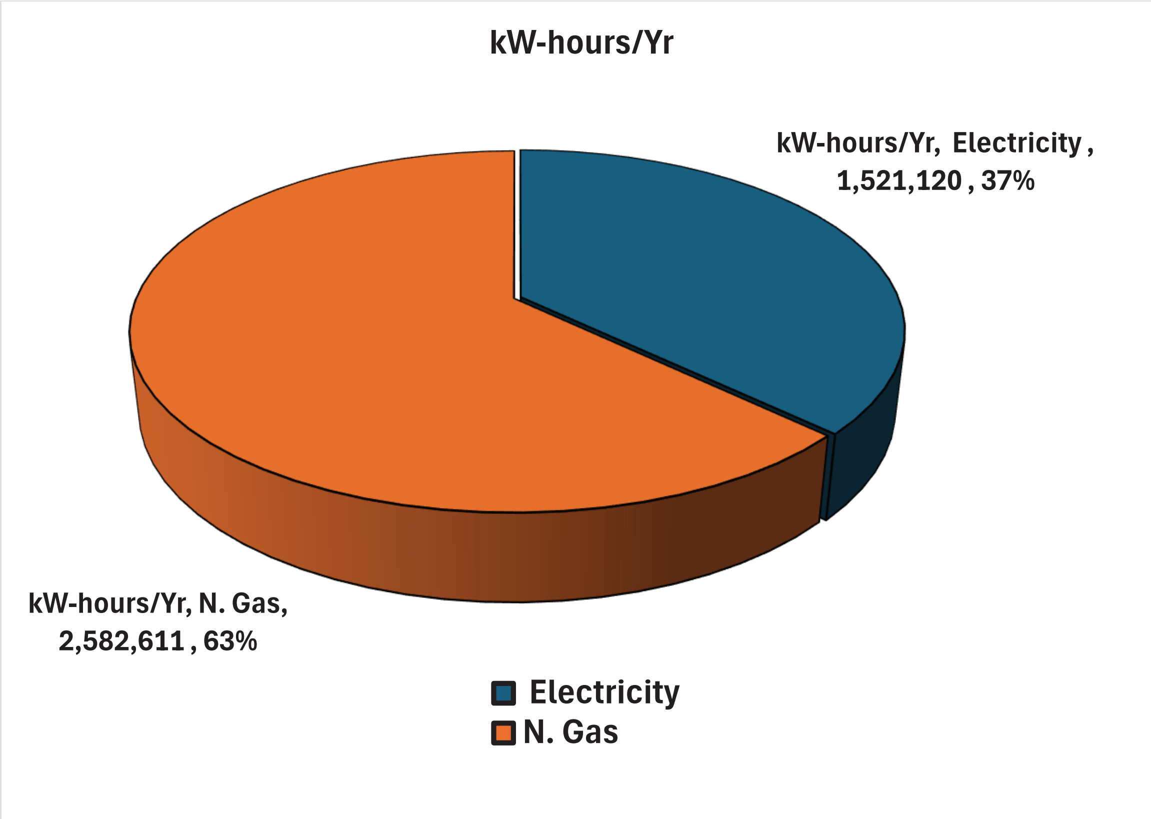

Fig. 1. Total energy breakdown

2. Discussion

This plan combines policy applications and project installations consisting of school, community, and utility mid-scale solar with storage. The applicable policies include:

- Community, public utility, and/or cooperative mid-scale solar installations for improved economies of scale — inside the distribution system, avoiding transmission issues
- Federal "direct pay incentives" via the U.S. Inflation Reduction Act (IRA)
- Local utility rebates
- School bonds, green bonds, and/or utility on-bill financing
- High load-factor time of use (TOU) electric rates
- Unlimited fair value net metering
- External benefits accounting for democratic, environmental, social, and economic categories (including economic multiplier benefits)
- Avoidance of market failures that negatively impact project developments

With mid-scale solar PV, whether owned by the school district, the public (municipal) utility, community, or cooperatively, the economies of scale for a 3- to 5-MW solar array

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provide a levelized price of 4 cents/kWh or lower — especially with the federal direct pay incentive (30%) or production incentive of 2.6 cents/kWh.

However, local ownership and control within the distribution system is critical, in contrast to outside power purchase agreement (PPA) projects. Solar projects under a PPA can eliminate the advantages of local solar distribution projects.

With locally owned projects, financial incentives can include rebates, tax credits, and non-taxable direct payments, on-bill financing, lower-interest school bonds, and green bond financing. This improves the economics for solar, wind, energy storage, fuel-switching, efficiency, and infrastructure upgrades. And these financial incentives internalize some of the heretofore unpaid environmental external costs.

As outlined in the Database of State Incentives for Renewables and Efficiency (2024), “Under the federal Inflation Reduction Act (IRA), there are 30% investment direct pay credits now available for infrastructure, assuming the renewable energy system is sized less than 5 MW per installation. This applies to interconnection property associated with the installation of renewable energy property with a maximum net output of not greater than 5 MW-AC to provide for the transmission and distribution of the electricity produced or stored by such property, and which are properly chargeable to the capital account of the taxpayer.

“The direct-pay option allows non-taxable entities to directly monetize certain tax credits. The provisions apply to nonprofits, a state or political subdivision and such applicable entities can elect to be treated as having made a tax payment equal to the value of the tax credit they would otherwise be eligible to claim. The entity can then claim a refund for the excess in taxes they are deemed to have paid. The option effectively makes this tax credit refundable for these nonprofit entities.”

Should the solar PV installation be community or cooperatively owned, in contrast to the public municipal utility, a fair value unlimited net metering policy should be implemented offsetting peak power grid purchases, roughly 9 cents per kWh or more.

Local ownership maximizes the democratic, environmental, and economic benefits by reducing additional costs associated with market imperfections. These include transaction costs, transmission interconnection costs, transmission fees, transmission efficiency losses (2% minimum, up to 10%), price markups, higher interest rates, permitting delays, long supply chain environmental impacts, potential low regional transmission market revenue prices (even negative on occasion), and loss of local grid optimization and harmonization.

Low-cost net energy is available by applying high load-factor rates offered to large primary customers, such as the “Primary Service-High Load Factor Rate I1”. See Figure 2.

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PRIMARY SERVICE-HIGH LOAD FACTOR

(Rate "I1")

Availability:

Open to any customer desiring primary voltage service for general use where the billing demand is 100 kW or more. This rate is not available for street lighting service or for resale purposes.

Nature of Service:

Alternating current, 60 hertz, single phase or three phase, the particular nature of the voltage in each case to be determined by the Department.

Where service is supplied at a nominal voltage of 15,000 volts or less, the customer shall furnish, install and maintain all necessary transforming, controlling and protective equipment.

Beginning July 1, 2014 any new customers must purchase and retain ownership of all necessary transforming, controlling and protective equipment, and, install and maintain this equipment at their expense. The customer is responsible for all costs and liability associated with the transforming, controlling and protective equipment.

Where the Department elects to measure the service at a nominal voltage of less than 2,400 volts, 3% will be added for billing purposes to the demand and energy measurements thus made.

Monthly Rate:

Customer Charge:	$200.00 per meter per month, plus
Capacity Charge:	$14.05 per kW of on-peak billing demand
Energy Charge:	6.26¢ per kWh for all kWh consumed during the on-peak period.
	5.06¢ per kWh for all kWh consumed during the off-peak period.

Power Service Cost Recovery:

This rate is subject to the Department's Power Service Cost Recovery.

High Load Factor Credit:

Monthly credits will be given to high load factor customers as follows:

Load Factor	% Credit on Total Billed Amount
90% - 100%	5%
80% - 89%	4%
70% - 79%	3%

Schedule of On-Peak and Off-Peak Hours

The following schedule shall apply Monday through Friday (except holidays designated by the Department). Weekends and holidays are off-peak.

On-Peak Hours:	10:00 a.m.	to	5:00 p.m.
Off-Peak Hours:	5:00 p.m.	to	10:00 a.m.

Fig. 2. Primary Service-High Load Factor, Rate I1

The I1 rate has a high monthly fixed fee ($200/mo), a peak period monthly demand charge of $14.05, an off-peak energy charge of 5.06 cents, and an on-peak charge of 6.26 cents per kWh. Customers with load factors over 90% receive a 5% credit on the total amount billed; load factors over 70% and 80% receive a 3% and 4% credit respectively. The monthly fixed fee is typical for primary-rate industrial customers with

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large transformers. If the monthly capacity charge of US $14.05 per kW of on-peak demand can be offset with smart controls, demand management, and solar PV, average retail electric prices can approximate 5 to 6 cents per kWh. Off-peak periods include all weekends (65 hours), holidays, and all but seven hours each weekday. In fact, 80% of the hours in a typical week are off-peak.

Building Characteristics

- School campus property: 90 acres (36 ha)
- Building roof: 210,000 ft^2 (19,520 m^2) (or 5 acres)
- Annual energy expense: $284,849
- Present annual kWh/year: 1,521,120
- Natural (fossil) gas kWh/year: 2,582,611 (based on 117,526 ccf gas)
- Total building annual energy kWh: 4,103,731
- Estimated school bus EV kWh/year: 60,300.
- Total kWh/year w/buses: 4,146,031
- Present peak kW demand: 346 kW

Fig. 3. School Area

Presently, the cost of fossil methane gas for heating is between US 4 and 5 cents per kWh, varying with the system efficiency (70% – 90%) and the delivered price of gas (US $1.00 +/- per CCF or therm). This cost comparison is for direct electric resistance heating, domestic hot water tanks, baseboard electric heating, and all other internal electric sources. With these low prices, off-peak thermal and electric energy storage can be cost-competitive. With the application of heat pumps for space heating and domestic hot water (DHW), the value of electricity for heating is cut 50% or more with a comparison thermal value of 2.5 to 3 cents/kWh. During on-peak periods (10 a.m. – 5 p.m. weekdays) solar energy will directly offset higher-cost electricity, avoiding demand charges and reducing overall electric prices.

This facility has two large boilers totaling 3.2 MWt (10.9 million BTU). To electrify the thermal system variable-controlled electric boilers and heaters with associated storage (hot water, salts, or hot bricks) in the range of 3 MWt can be pre-fed into the existing systems with little change. Such electric boilers and heaters can also be used for power quality management.

Project characteristics of this solar CHP system (see Figure 4):

- Solar PV for 100% net kWh: 3,400 KWac (23 acres of 90 acres – 25% of the property)
- 3 MWt electric boiler/heater (10 million BTU) with variable output controls.
- Thermal storage: Electric hot bricks and/or hot water.
- Electric battery storage: stationary Li-ion, EV buses, and service vehicles.

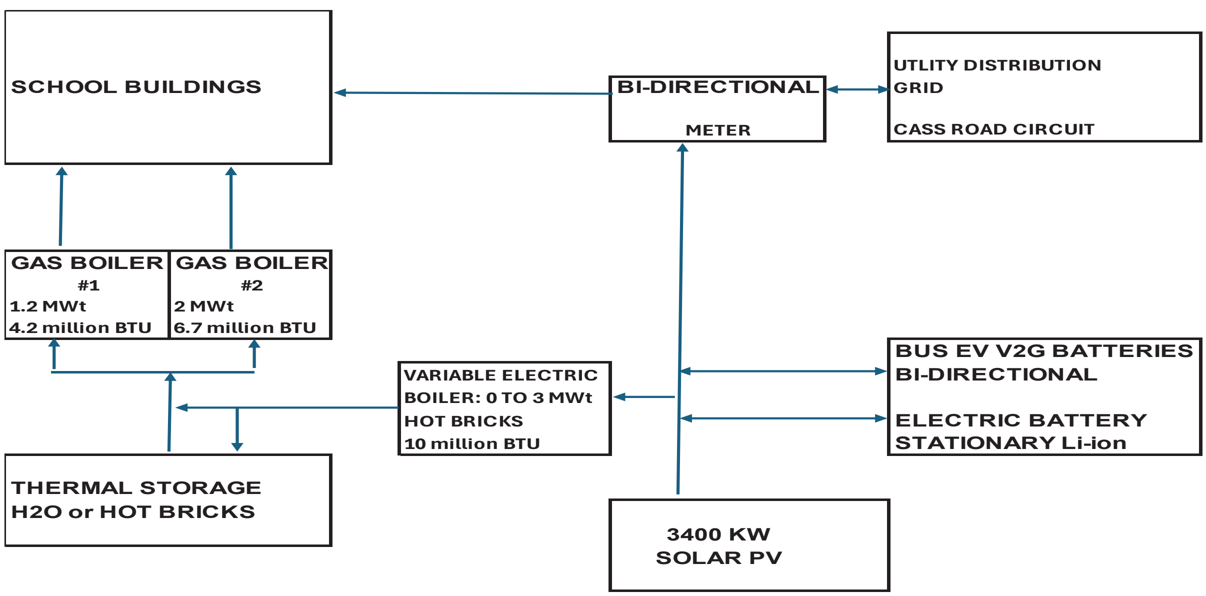

Fig. 4. Project System Components and Flows

To achieve 100% solar PV generation the proposed 3,400 kWac peak solar arrays on the building and grounds must have interconnection capacity on the distribution circuit. Preliminary examination, based on recent distribution grid analysis, indicates this is feasible without significant modifications to the distribution circuit shown in Figure 5, circuit CD 31 on the Cass Road substation.

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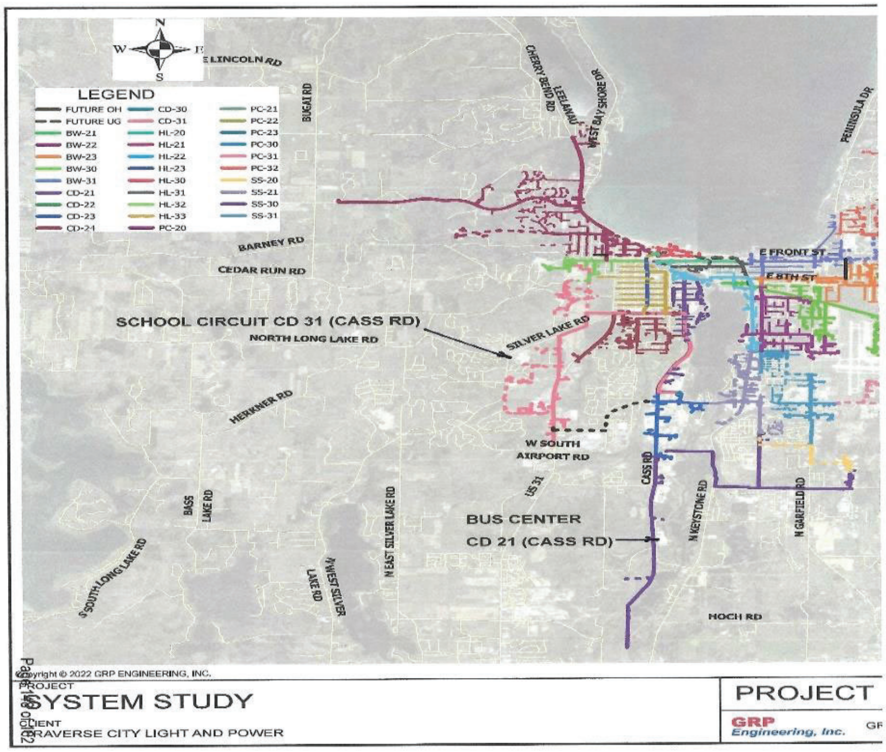

Fig. 5. Distribution Circuits

The transformer loads on the circuit are shown in the following Table 1 where column (f) indicates the Cass #2 transformer is presently loaded on average at <30%, 6.52 MVA of the 22.4 MVA rating, columns (a), (e), and (f).

LOAD STUDY DATA FROM ENGINEERING REPORT					SMILEY EXTRAPOLATION OF DATA					
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
Substation	Trans	Rating (MVA)	Summer Peak Loading (MVA)	% Max	Net of 100% (MVA)	Avg Loading at 40/70 (MVA)*	% Avg	Net of 45% Safety Factor**	45% Avg Load (MVA)	Avg Net Load at 45% (MVA)
Barlow	#1	13.4/17.9/22.4	6.95	31.0%	15.45	3.97	17.7%	27.3%	10.08	6.11
Barlow	#2	13.4/17.9/22.4	7.54	33.7%	14.86	4.31	19.2%	25.8%	10.08	5.77
Cass	#1	13.4/17.9	7.57	42.3%	10.33	4.33	24.2%	20.8%	8.055	3.73
Cass	#2	13.4/17.9/22.4	11.41	50.9%	10.99	6.52	29.1%	15.9%	10.08	3.56
Parsons	#1	13.4/17.9	7.00	39.1%	10.90	4.00	22.3%	22.7%	8.055	4.06
Parsons	#2	13.4/17.9/22.4	11.58	51.7%	10.82	6.62	29.5%	15.5%	10.08	3.46
Hall	#1	22.4/29.9/37.3	9.57	25.7%	27.73	5.47	14.7%	30.3%	16.785	11.32
Hall	#2	22.4/29.9/37.3	11.03	29.6%	26.27	6.30	16.9%	28.1%	16.785	10.48
South	#1	13.4/17.9/22.4	3.63	16.2%	18.77	2.07	9.3%	35.7%	10.08	8.01
South	#2	13.4/17.9/22.4	4.77	21.3%	17.63	2.73	12.2%	32.8%	10.08	7.35
		244.8	81.05		163.75	46.31	19.5%	25.5%	110.16	63.85

Table 1. Transformer loading – peak summer and average

The box on the left in Table 1 is data provided from the engineering study "2012 System Load Study and Analysis" (GRP Engineering, Inc. 2021). It contains transformer ratings and summer peak loading, with a percentage of full load capacity, column (c). Column (d) results from subtracting the summer peak, for example, Cass #2 of 11.41 MVA (b), from the rated 22.4 MVA transformer (a), resulting in a net of 10.99 MVA, or 50.9% of the full load rating. The box on the right in Table 1 is an extrapolation by the author from the system load study. Column (e) is the average load compared to the peak load, assuming 40 MW (MVA) is the annual average, and 70 MW (MVA) is the annual peak. While the actual annual average is roughly 35 MW, 40 MW is assumed for a margin of safety.

For example, the Cass #2 transformer summer peak of 11.41 MVA (b), multiplied times (40/70), results in an average loading of 6.52 MVA shown in column (e) and an average percentage load of 29.1% shown in column (f). This is well under the 45% safety limit, a limit set to provide transformer circuit emergency backup. Column (h) shows the Cass #2 transformer maximum 45% target capacity of 10.08 MVA, which is 3.56 MVA (i) over the average of 6.52 MVA (e). This provides an average excess capacity of 3.56 or 15.9%, while meeting the 45% safety target.

Summarizing the solar PV solution:

- The solar PV should generate 100% annual kWh – 4,103,731.
- A 3,400 kWac peak solar array is projected assuming local solar resources derived from the National Renewable Energy Laboratory "PV Watts" methodology.
- The solar array plan includes installations on parking lots, fields, and building roofs totaling 23 acres (9.2 ha) of the 90-acre (36 ha) property.
- A peak period (10 a.m. to 5 p.m. weekdays) "peak shaving" program will be implemented to eliminate demand charges weekdays, totaling 35 hours per week. Even at 10% of solar PV output, or 340 kW (cloudy/snow days), peak demand fees can be negated — eliminating the $14.05 kW/mo. demand charge, providing an energy only cost of 5 to 6 cents/kWh.
- Peak shave and distribute excess summer solar at high value demand periods.
- This solar PV system peak capacity represents 10% of the entire utility average 35 MW load and 5% of the peak summer load!

The following Figure 6 shows the monthly energy consumption, including combined thermal and electric loads (blue line) and monthly projected solar PV generation (orange line). Beginning in mid-March, monthly solar PV exceeds the building energy use until October, when heating loads increase. During the period when solar PV exceeds energy consumption, the value of solar should be set at a fair price such as a minimum of 9 to 10 cents/kWh.

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The solar PV system must always be dispatched to eliminate any peak demand charges during the 10 a.m. to 5 p.m. weekday peak period. Historically, electric-only demand at the school had a peak of roughly 346 kW. With solar PV output of only 10% of the 3,400 kWac, the solar output of 340 kWac approximates the historic annual peak. During the winter months, when snow cover can impact fixed solar arrays that are inaccessible, the proposed ground mount, roof top, and single axis tilting arrays can be cleared of snow.

During off-peak periods, with or without solar PV, excess energy required (not from storage) can be purchased at the low off-peak price of 5 to 6 cents per kWh. The spread between selling solar high, for example 9 to 10 cents/kWh and exchanging energy at a low price of 5 to 6 cents/kWh, provides for additional net revenues. With additional net revenues from the solar and storage system, the total energy costs of operation will be reduced.

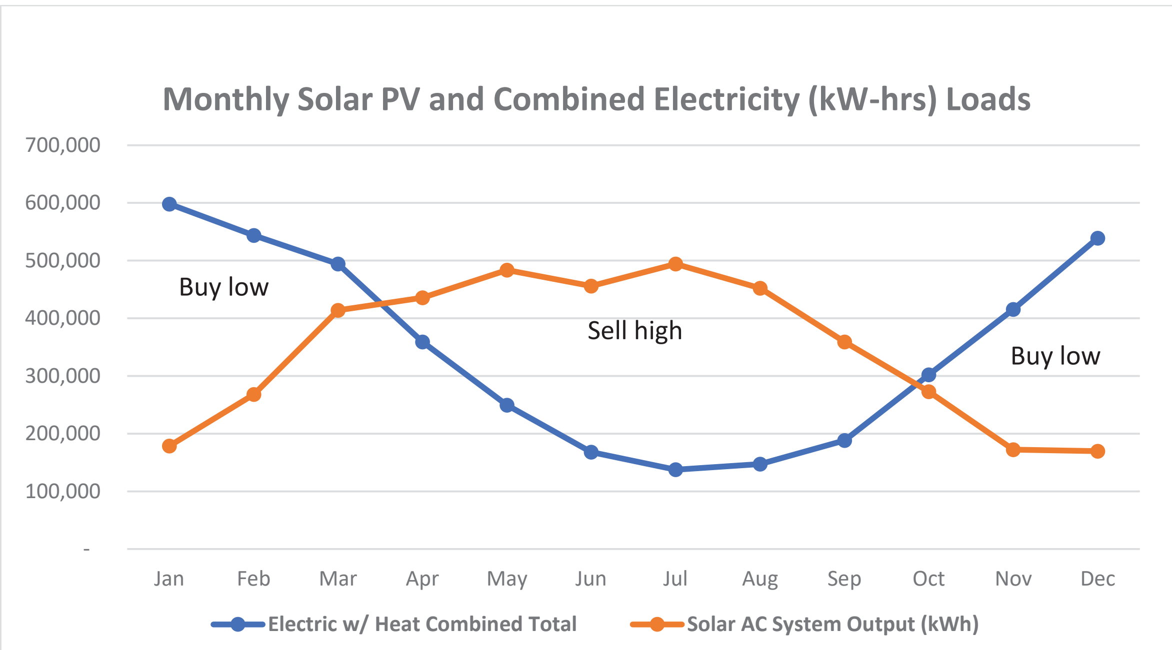

Fig. 6

Four types of battery storage systems are considered:

- EV V2G vehicles
- Stationary lithium-ion
- Hot water
- Advanced hot bricks

The value of EV V2G school buses and service vehicles cannot be overstated. With off-peak electricity priced between 5 and 6 cents per kWh, the comparative cost of fuel is between \$0.56 and \$0.67 per gallon (\$0.15 to \$0.18 per liter) petroleum equivalent for buses. For EV service and staff vehicles with higher efficiency than buses with 3 to 3.5

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miles (5 to 5.75 km) per kWh, the comparative fuel cost is $0.43 to $0.50 per gasoline gallon ($.11 to $.13 per liter).

Six of the buses analyzed, each with a 60-kW dispatch capability to the grid and net 218-kWh capacity, can provide a 360-kW peak and 1,308 kWh per day exceeding the average seven-hour load of 1,214 kWh. This roughly matches a stationary battery system, with no added cost. In addition to peak and cost shaving, energy discharged into the grid with the V2G school buses provides additional revenues, and these EV buses and service vehicles, with much lower fuel and maintenance costs, pay for themselves.

In addition, local rebates and federal incentives are available and are highly justified as the external health and climate benefits are significant. A recent study by the U.S. National Academy of Sciences, “Adopting electric school buses in the United States: Health and climate benefits” calculated the average diesel bus would generate a benefit of US $84,000 per bus and cut 181 metric tons of carbon dioxide emissions and reduce childhood deaths and asthma cases (Choma, Robinson & Nadeau, 2024). Under the recent U.S. Environmental Protection Agency Clean School Bus Program, US $5 billion in funds have been designated to support public school districts and tribal organizations.

With V2G EVs, stationary electric battery storage can be eliminated. However, for security reasons and to eliminate the expense of a fossil fuel standby generator, some minimum fixed storage can be installed. For stationary battery storage, a typical 20-foot container consisting of a 250-kW peak output inverter with 1300 kWh stated energy, priced under $400/kWh can be considered. With no sun and demand management, the school can operate without the grid for an extended period.

Charging thermal storage is accomplished either with an electric boiler (for hot water) or direct electric resistance with hot bricks (for steam) during off-peak periods. The hot water or hot brick storage should have the capacity to heat the building during the weekday seven-hour peak period. Hot brick systems store energy at high temperatures (1,000°C/1,832°F) and can provide either steam, hot water, or hot air. Importantly, no significant mechanical HVAC (heating, ventilation, air conditioning) changes will be required inside the school. When hot water or steam is supplied, the *fossil gas will never fire in the boilers*.

3. Conclusion

The school should implement a system to manage loads with solar PV, electric heating, and storage making the school a “high load factor” consumer (90% +/-) qualifying for low-cost electricity of 5 to 6 cents/kWh under the “Primary Service-High Load Factor Rate I1, competitive with fossil methane gas. The solar, storage, and demand management system must never allow positive kW demand during the peak periods. The school should install electric heating with thermal storage, both hot water and hot

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rocks, and directly feed hot water or steam into the existing fossil gas boilers, shutting the gas off, with this simple retrofit. The building mechanical heating system components will remain the same, whether hot water or steam distribution, thermostats and zone controls, boiler circuit valves, and pumps.

The school should only draw high electric load heating off-peak (80% of hours) and put any excess solar energy in storage. When storage is full, solar can be sold into the grid. 3,400 KWac peak solar will benefit the entire distribution circuit, not just the school, providing high-value peak period solar for other utility consumers, off-loading circuit transformers, reducing transmission deliveries, costs, and efficiency losses, while providing improved grid voltage control.

Working inside the utility “distribution” system avoids ISOs, the independent system operators, with their structural, financial, market, and institutional barriers. The school and utility will create direct competition between cheap solar electricity and fossil “natural” gas, petroleum, gasoline, diesel, LP gas, and fuel oil. This keeps energy savings and solar income local with economic multiplier and environmental benefits.

With school projects like this the community and electric utility can implement and apply their own local policies including GHG fees, renewable energy credits, TOU rates, rebates, on-bill financing, and net metering. With school and green bonds, these policies can be used to incentivize local projects, community solar, fuel switching, smart grids with broadband, energy efficiency, and infrastructure upgrades.

Construction inside the local distribution grid boosts local employment opportunities for utility technicians, solar installers; and electric, mechanical, and general contractors. School projects such as this with a focus on local ownership versus PPA’s enhance democracy and justice putting energy, money, and power into local citizens’ hands.

Schools can be the catalyst for accelerating renewable energy.

Conflict of Interest

There are no conflicts of interest to disclose.

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