Whole Home Electrification Retrofits

Why Stop at Zero Net Carbon?
Electricity is Cheap.
Go Negative!

A Green White Paper

By Barry Cinnamon
Cinnamon Energy Systems, Inc.

1. Introduction

I'm writing this in San Jose during a Mars-like red sky, light ash occasionally falling, and a faint smell of smoke in the air. Solar output has been down by 60% even though the fires are at least 50 miles from here.

Some people say this is the new normal. In all likelihood it will get worse as we experience more extreme weather events and sea levels rise from melting ice sheets. Many people in California are literally powerless since our utility infrastructure is failing to keep pace with the effects of climate change, magnified by our society's increasing electric power needs.

Altruism aside, generation is less expensive than conservation for existing buildings. It is more cost effective to add solar and storage than to improve the efficiency of the building shell, or to replace existing HVAC equipment prior to its end of life with new high efficiency equipment.

Fortunately – with current solar, battery and heat pump technology -- every building with a sunny roof under two stories can be a net generator of energy. Essentially carbon negative! Moreover, with grid-connected batteries, buildings can easily provide the resiliency that our grid needs during power shortages and blackouts.

2. Time to Burn That Bridge to Natural Gas

Former DOE Secretary Ernie Moniz positioned natural gas as the bridge to renewables. We've crossed that bridge; on-site renewables are now cheaper than natural gas for all applications except industrial process heat and long-haul trucking.

Humanity is facing an "all hands on deck" climate change emergency. Since rooftop solar and storage can be installed quickly and inexpensively, we should not stop at carbon zero – we should strive to make all buildings as carbon negative as quickly as possible.

Customer economics for on-site renewables are compelling. Consider a home that uses 1,000 therms of natural gas for space heating per year; at $2/therm that works out to $2,000/yr. Current heat pumps would consume 8,300 kwh/yr to provide the same amount of heat; at $0.30/kwh that works out to about $2,500 for electricity. However, with rooftop solar in the equation at an average rate of $0.10/kwh, annual operating costs for the heat pump would be $830. Similar energy math demonstrates that a heat pump water heater is also superior to a natural gas water heater.

Overcoming our addiction to fossil fuels is the challenge since buildings consume 28% of total energy use in California. Unfortunately, there is limited literature on real-world electrification experiences of existing buildings. Is a whole home electrification retrofit practical, cost effective and comfortable? Is it possible for older buildings to generate excess energy – essentially carbon negative -- on an annual basis?

3. Electrification Retrofit Measures

The following case study describes the complete electrification of a 50-year old San Jose house, including generation with rooftop solar and energy storage with batteries. No more fossil fuels.

Along the way I encountered a few stumbling blocks, but also got some very positive surprises. The electrification measures that were completed were broken down into three basic stages: Preparation, Generation and Conversion, as described below.

3.1. Preparation - Low Hanging Fruit

Conventional wisdom suggests starting with an energy audit. The author has used energy audit programs for over 40 years, including the DOE’s Home Energy Advisor program. Unfortunately, these programs rarely account for local utility rates, solar and storage incentives, low solar and storage costs, as well as new heat pump and appliance technology.

My contrarian advice is to punt the energy audit and focus instead on the low hanging fruit -- generally LED lighting; sealing leaky windows, doors and ductwork; and operating electrical appliances efficiently when electric rates are lowest.

Nevertheless, there are some products and services that provide real-time reporting of electricity consumption; these services are quite helpful in identifying and subsequently reducing building electricity use.

For this project it did not make economic sense to re-insulate the walls or upgrade the remaining single-glazed windows. However, the ancient attic insulation was vacuumed out and 18” of blown in cellulose was added, raising the R value from less than 7 to 60. It was a no-brainer to replace all the incandescent and CFL bulbs with LEDs. The old single speed pool pump was replaced with a new variable speed pump that was so quiet that it could be operated at night when electric rates were low. Eliminating vampire power loads, using a setback thermostat, and operating appliances at off-peak times generated additional savings.

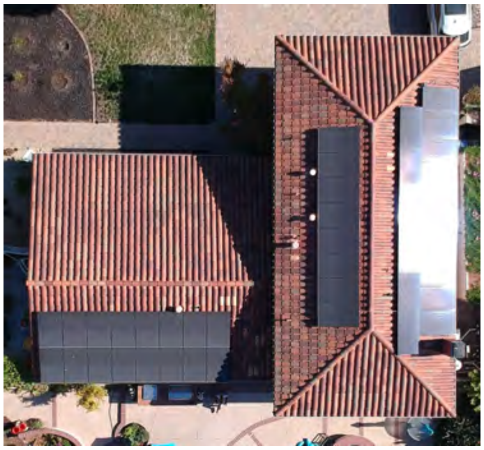
R-60 Attic Insulation

Variable Speed Pool Pump

3.2. Generation – Solar and Storage
Once the easy and cheap energy efficiency measures have been implemented, in almost every case the next step is to generate electricity with a rooftop solar power system. The payback for these systems is faster than upgrading functional appliances, adding additional wall insulation, or replacing doors and windows.

Based on energy consumption of similar homes and appliances, it was estimated that about 10 kw of rooftop PV and 20 kwh of battery storage would result in a zero electric bill – including HVAC, water heating, cooking, pool pumps and one electric vehicle.

Current electric rates are $0.48/kwh from 4-9 PM and $0.17/kwh during most other times. By storing solar energy in the battery during the day (instead of selling it back to the grid at lower mid-day rates) and then using that energy at night, homeowners with batteries are able to avoid high peak electric rates. Plus there is the obvious benefit of having backup power for essential loads in the house during blackouts caused by utility equipment failures, fires and public safety power shutoffs.



Rooftop Solar

2 Storage Batteries, Inverter with EV Charger, Storage Inverter, Solar-Ready Service Panel

3.3. Conversion – Replace All Gas Appliances

It is rarely cost-effective to purchase new, high-efficiency appliances to replace existing, functional appliances. Better to wait until the old appliances die, unless the efficiency of the existing appliance is extremely low or there are other reasons (such as comfort, noise or compelling environmental guilt).

In preparation for this complete electrification project, the original 200 amp main service panel was upgraded to a new "solar ready" service panel. Since this work was done at the same time as the solar and battery installation, the federal tax credit applied to this upgrade.

Although the existing gas furnace was functional, the air conditioning compressor did not operate reliably and the ductwork in the house was in poor condition. To provide both heating and air conditioning, a two zone heat pump system was installed, along with two fan units, new ductwork, and two internet-connected thermostats. Note that this was not a "split" ductless system, but a traditional ducted system using the existing air vent layouts in each room. In operation this high efficiency inverter-based HVAC system was almost impossible to hear. Moreover, the outdoor compressor unit occupied less space than the existing cylindrical AC compressor, and removal of the old gas furnace and venting system freed up additional space in the garage.

San Jose has a rebate program to encourage the installation of heat pump water heaters. The existing 65 gallon gas hot water heater was replaced with a 65 gallon heat pump water heater. Since time-of-use rates provided additional benefits to doing laundry during off-peak times, the gas dryer was replaced with an electric dryer.

After these appliance changes were made, the antique gas cooktop was the only gas appliance left in the house. An induction cooktop was installed to replace this gas range, thereby completing the electrification of the home. However, two rarely used outdoor gas appliances remained: the gas pool/spa heater and the gas BBQ. Since these polluting gas appliances were rarely used – and with no compelling electric options -- they were left in place.

Heat Pump HVAC

Heat Pump DHW

Induction Cooktop

4. Electrification Retrofit by the Numbers

The table below summarizes the electrification measures, installation costs, energy savings and dollar savings for each retrofitted appliance.

Electrification Measure	Net Cost	Electricity Savings kwh/yr	Electricity Savings $/yr (3)	Gas Savings Therms/yr	Gas Savings $/yr (4)
VS pool pump	$1,500	1,400	$ 420		
Attic Insulation	$3,400	300	$ 90	182	$363
LED lights, home controls	$300	1,752	$ 526		
Rooftop solar 10 kw (1)	$24,050	14,500	$ 4,350		
Energy storage 20 kwh (1)	$16,700		$ 900		
Heat pump HVAC (5)	$26,000	(8,297)	$ (830)	1,000	$2,000
Heat pump DHW (2)(5)	$1,600	(1,659)	$ (166)	200	$400
Totals	$73,550	7,996	$ 5,290	1,382	$2,763
Simple Payback (years)	9.1				
Comfort/Safety Measure					
200 amp panel replacement(1)	$4,200				
EV charger on solar inverter (1)	$630				
Induction cooktop	$1,700				
NOTES:					
1. 30% ITC					
2. $2,000 city rebate for heat pump					
3. $0.30/kwh grid electricity, $0.10/kwh solar electricity after solar+storage installation					
4. $2/therm incremental consumption					
5. 80% natural gas efficiency, 300% heat pump efficiency					

5. Lessons Learned

5.1. Electric Service Upgrades Usually Required

Homes that are fully electrified – heat pump HVAC, heat pump water heater, electric stove/oven, electric dryer, solar, storage, EV – cannot get by on smaller 100 amp or 125 amp electric services. Costs for individual consumers can range from $5k for a simple electric service upgrade to well over $20k if underground wiring or transformers need to be updated. Up-front utility engineering fees and delays of six months or more are typical. Cities and states that plan to electrify existing buildings must find ways to proactively streamline and reduce costs for electric service upgrades. Homeowners must prepare for electrification so that they can replace their gas appliances quickly when they fail. No homeowner in their right mind would wait three to six months without heat or hot water for an electrical upgrade. Without a 200 amp electric service, homeowners will simply replace broken natural gas appliances with new natural gas appliances.

5.2. Inverter-based Zoned Heat Pumps Pair Best with Solar + Storage

Heat pump technology has advanced rapidly. However, HVAC contractors may not understand the integration issues with solar, storage and backup power. Some quotes that were received recommended natural gas or electric backup heat, as well as older and less efficient heat pump technology that would not operate during a power outage. The multi-zone inverter-based heat pump that was installed is compact, efficient, and has a low operating and startup current draw.

5.3. Heat Pump Water Heaters Unfamiliar to Many Contractors

Plumbers sometimes confused heat pump water heaters with flash water heaters or conventional electric tank water heaters (which are actually prohibited in some areas). The installation of a heat pump water heater may require an additional 30 amp electric circuit – which is an electrical task that is outside the scope of work of conventional plumbers.

5.4. Solar and Battery System Sizing

Sizing a solar system is fairly easy if historic energy data is used. More complicated engineering calculations are necessary to determine the additional solar capacity required when a heat pump water heater, HVAC system or EV is being considered. Battery system design must consider both the power available from the battery as well as the energy capacity of the battery, and these power/energy requirements depend on the size of the solar system as well as the appliances expected to be operating during a power outage.

5.5. Software and Communication Protocols Tricky to Configure

Although the hardware for “all electric” homes is reliable, software and communication protocols are still at an early stage from most vendors. These systems, and their respective cell phone apps, rarely talk to each other. The biggest challenges in this project related to configuring these apps and getting them to communicate reliably.

This project involved the work of seven different types of specialty contractors: insulation, pool, electric, solar/storage, HVAC, plumbing and carpentry. Homeowners who are not familiar with the engineering tradeoffs should consider contacting other homeowners who have electrified their homes, or hiring a consultant who understands the available equipment choices -- as well as local codes, electric rates and incentives.

5.6. Significant Comfort and Safety Benefits

As a result of this electrification project, the electrical system is safer; HVAC, DHW and cooking create no emissions or fire danger; heating and cooling is quiet and more comfortable; and backup power is automatic, silent and safe.

5.7. Operational Recap After One Year

After one year of operation, it is clear that a 10 kw rooftop solar system would have been the right size. However, during the installation additional panels were installed, raising the system size to 12.8 kw. After the first year of operation the system generated 17,404 kwh, with an excess of 7,788 kwh per the utility bill – also reflecting the electrification measures described above. Excess energy would have been much less if two EVs were charged at home. Maximum current demand from the utility was 32 amps, occurring during the winter around midnight when the battery was depleted and heating was required. Minimum current demand was -43 amps, occurring around noon on cool, sunny spring/summer days. 20 kwh of energy storage provided enough capacity to avoid peak energy use on 335 out of 365 days of the year. Only on very hot, smoky or cloudy days was it necessary to draw utility power during peak times.

6. Policy Recommendations

The tangible impacts of climate change are compelling California to electrify buildings and transportation on an increasingly short time frame. Not only do all gas appliances need to be replaced, but inexpensive and reliable electricity is also essential. Upgrading existing buildings with on-site solar and storage is the fastest and least expensive means to this end. Since the incremental cost to add more solar and storage is relatively low, encouraging buildings to go carbon negative is beneficial to the environment, the grid, and ratepayers as a whole.

Effective transitions of this magnitude are accelerated by favorable customer economics. From a financial standpoint there is private capital from both building owners and the banking industry. However, this transition is being delayed and side-tracked by incumbent utilities. The desire for Investor Owned Utilities (IOU) to generate increasing profits is fundamentally at odds with California's need for a rapid transition to safe and affordable electricity; the only solution is to overhaul the utility business model…not an easy task.

The real world findings from this project suggest three key policies to improve the economics and accelerate building electrification:

6.1. Fairly Compensate Host Customers

Customers and investors must continue to receive fair compensation for both the energy (kwh) and power (kw) that they provide to the grid. They should not be penalized for the investments they make in solar and storage, especially as these millions of solar and battery systems provide energy and power during power shortages and blackouts. Lost profits to utility investors from decreased sales and assets are simply the result of the superior economics of distributed solar and storage.

6.2. Eliminate Paperwork, Simplify Incentives and Automate Interconnection

These needless bureaucratic costs add 30% or more to electrification projects, particularly those related to improvements that interact with the electric grid. Management of incentives and interconnections must be taken out of the hands of incumbent industries who are obviously opposed to these self-generation and conservation measures. It is ludicrous that IOUs so deliberately and effectively mismanage incentive programs that the costs of processing this paperwork often exceeds the value of the incentive itself. Interconnection delays of four to six months are typical for battery projects, commensurately reducing the financial benefits to customers (a five month delay with a $300 electric bill means that an additional $1,500 goes to the utility instead of being saved by the customer).

6.3. Upgrade Residential Electrical Infrastructure

The process to upgrade a home's electrical service is broken and must be overhauled. When a homeowner's hot water heater or furnace dies, or they purchase an electric vehicle, or they want to install a rooftop solar to meet 100%+ of their electrical needs, or they want to install a battery for backup power and grid support services, they cannot wait six months and spend $5k-$20k for their utility to get around to a service upgrade. These extra costs and delays often completely derail homeowner efforts to electrify. A better course of action for governments would be to coordinate electric service upgrades to groups of nearby homes. Homeowners would not have to navigate the opaque set of utility and city rules for upgrades, one contractor could be selected to do the expensive underground and aerial electrical work in a neighborhood, and homeowners could then electrify their homes when convenient.

7. Conclusion

By accelerating California’s electrification transition, we have the potential to avoid the worst impacts of global warming -- while at the same time improving the environment and economy. Electrification retrofits for existing buildings can rapidly reduce greenhouse gas emissions. Moreover, for relatively low incremental costs these buildings can generate more energy than they consume, essentially becoming carbon negative.

However, incumbent energy industries and related interest continue to **block** (for example, prohibiting battery net metering, even when there are afternoon and evening power shortages), **delay** (six months or more for permits and interconnections) and **add costs** (high fees and unfavorable rate plans) to these electrification efforts. Nevertheless, technology, financing and favorable customer economics are available to accelerate this transition with the right policies in place.