Residential Solar Lessons Learned

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July 10, 2025

1. Introduction

We started planning for installing a residential solar electrical power system in December 2023. Our roof needed replacement, and if we were going to install solar, this appeared to be a good time to do so. Initial contact with solar providers was to inquire about anything special I should specify when we had the roof installed. Of course, the solar providers tried to go beyond this simple inquiry and sell a system.

Basically, I found that there really wasn't anything special that needed to be done with the roof installation. The new roof was installed in February 2024. From December 2023 to May 2024, I worked with three (then two) solar providers to understand their systems and make a choice. In early May 2024 I obtained Home Owner Association (HOA) approval for my plans (I still had not decided which company to go with, but the two remaining solutions were similar enough for HOA purposes). In May 2024 I signed the contract with Sky NRG Solar Inc.; Installation started in late May and completed in early June 2024. In June 2024, my application for Net Metering with Dominion Energy was approved and I could commence operating the system in the manner intended. I also registered to sell Solar Renewable Energy Credits (SREC) via SRECTrade; I started receiving SREC payments in the fall of 2024. In July 2024, I applied to Fairfax County for a real estate tax exemption of the solar installation; for a period of five years, the cost of the solar installation is deducted from the assessed value of the house for the purpose of calculating real estate taxes. Finally, I took advantage of the 30% federal tax credit for the solar installation.

2. Motivation for residential solar installation

The solar installation should reflect your reasons for investing in solar. The cost and capability of the installation can vary significantly. For this document, I will concentrate on the following motivations:

a. Minimize utility costs / maximize return on investment.
b. Ability to generate and use electrical power when off-grid (power outage).
c. Minimize dependence on utility power.

The biggest differentiation among the three motivation is capability (or presence) of energy storage (batteries) as part of the solar installation.

2.1 Minimize utility costs / maximize return on investment (ROI)

If ROI is the only motivation, then installing solar panels without any energy storage is likely the best option assuming Net Metering continues for the life of the solar installation. In Net Metering, when more power is produced by the solar installation than used, the excess is provided back to the grid (utility company); when not enough is produced, the deficit is provided by the grid. With Net Metering in Virginia, one is charged for the difference between what was provided by and what was provided to the grid (on a one kWh for one kWh basis). In months where more electricity is produced than consumed, the excess production can be carried over to offset deficits in future months. There is a limit to how much can be carried over, but I have not reached that limit.

Figures 1-4 illustrate that peak solar power production in general does not line-up with peak electrical power consumption. Peak production is typically between 8:00 am and 4:00 pm while peak consumption is in the afternoon and evening hours. The major electrical loads are our EV chargers (We have two Plug in Hybrid-Electric Vehicles - PHEVs), air conditioner compressor, oven, and clothes dryer. We typically use all but the clothes dryer in the afternoon after peak solar production.

With Net Metering, the grid provides the energy buffer to economically account for the mismatch in the timing of production and consumption. Net Metering however, is not guaranteed; the utility can always change the rules. For example, the utility may elect to charge for any power they provide when consumption is greater than generation; any power surplus provided to the utility is credited at a lower rate or ignored for billing purposes. Without the current Net Metering rules in Virginia, the ROI is significantly reduced. (Net Metering in California charges more for kWh the utility provides than the utility credits for what it receives)

Functionally, Net Metering is not needed if sufficient energy storage is added to the system. Unfortunately, energy storage is also expensive – making ROI more difficult. In early 2024, the cost of 10 kWh of energy was on the order of $18,000. For us, should Net Metering end, we would likely need between 25 and 30 kWh of energy storage capacity to take advantage of the majority of our solar production capability (We actually have 15 kWh; I assume we will still be able to add additional energy storage should Net Metering end). Note that regularly charging and discharging the batteries will cause them to wear out faster; batteries have a limited number of charge-discharge cycles.

If necessary, we could reduce the amount of required energy storage by charging our EVs, using the oven, and doing laundry during the time of peak production. We could also "super cool" our house during the period of peak production to reduce the need for air conditioning in the late afternoon and evening. Right now, with Net Metering, we don't do so because it is not necessary.

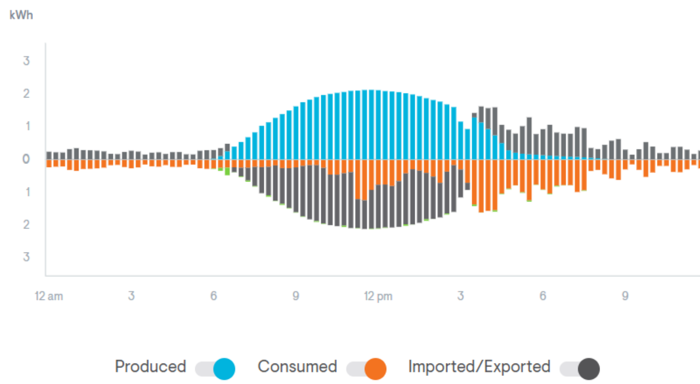

Figure 1: July 5, 2025 Sunny Summer Day

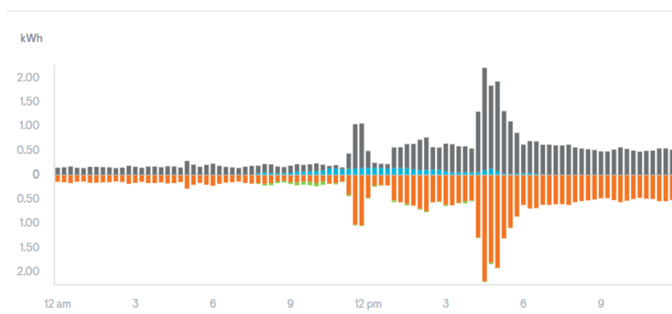

Figure 2: April 11, 2025: Rainy Spring Day

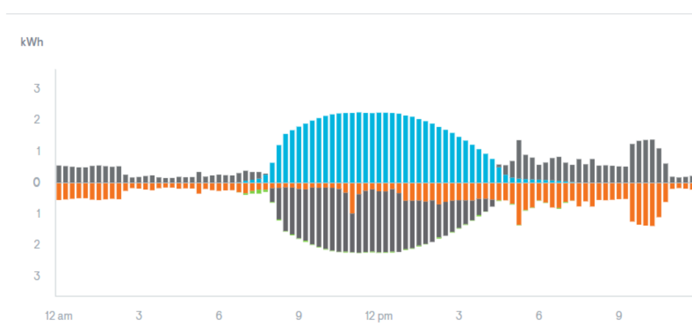

Figure 3: April 9, 2025: Sunny Spring Day

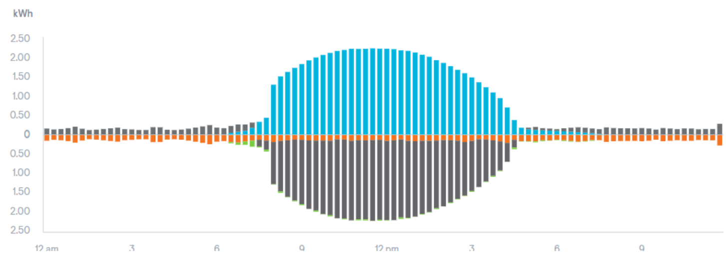

Figure 4: April 28, 2025: Sunny Vacation Day

The ROI depends on a number of assumptions as to what to include and exclude. Possible elements of the ROI calculation include

a. The direct cost of the solar installation.
b. Annual value of electricity produced. (Depends on projections of the cost to purchase kWh from the utility, whether Net Metering will continue and in what form, and the estimated amount of electricity produced)
c. 30% tax credit
d. Value of SRECs. (Will SRECs disappear or lose all value in the future?)
e. Impact on real estate taxes (Does the solar installation impact the assessed value? Impact of 5 year deduction of installation cost on real estate tax)
f. Impact on value of house

The last two elements can really skew the ROI results. In any case, considerable uncertainty exists in the estimates for most of the ROI elements. One should perform a sensitivity analysis to determine the likelihood of a favorable ROI. Remember that neither the most optimistic nor the most pessimistic estimate is probable.

2.2 Ability to generate and use electrical power when off-grid (power outage).

With the technology available in early 2024, it was not possible to operate the solar installation when off-grid without having energy storage. This means that should the power go out without energy storage, the solar system shuts off; the house goes dark. I'm not sure why this is the case, as far as I know, physics does not prevent the solar system from functioning when off grid. Nevertheless, one has to live with the capabilities that are commercially available. Furthermore, having a battery provides backup power during the night and other times that there is not enough solar power.

To be able to take advantage of the solar installation when off-grid, energy storage is currently required. Energy storage is rated both in terms of energy (kWh) and power (kW). The total power of all the energy storage should be sufficient to power the peak load minus any loads that are shed (see below). The total energy (and the power demand after load shedding) determines how long power can be provided until the energy is depleted.

Prior to our solar installation, we had a whole house generator (20 kW) powered by natural gas. Integrating this generator into the solar installation enables us to recharge the battery from the generator when it is depleted. Because of this, the energy rating of the battery was of secondary importance to us; the power rating was more important.

In our installation we have three battery units, each rated for 5 kWh and 3.84 kW for a total of 15 kWh and 11.5 kW. After load shedding, I anticipate our peak load is no more than 10 kW. The original proposal only included two battery units, but I was not convinced the 7.7 kW would be sufficient to supply the peak load. Our election not to include the air conditioner compressor in load shedding contributed to a higher peak load than originally estimated. (We want to stay cool in the summer no matter what!)

If you don't have or intend to have a generator, you should consider having a higher total energy rating and incorporating more aggressive load shedding to reduce both the peak power demand and the total electrical load.

2.3 Minimize dependence on utility power.

The solar installation reduces our dependence on utility power. This protects us from future price volatility in electrical rates. We are in uncertain times and our energy infrastructure as a nation is sensitive to disruptions that can lead to price volatility.

During power outages we previously depended on our natural gas powered whole house generator. The probability of losing both natural gas service and electrical power service at the same time was low. In recent years however, electrical power generation in the United States has increasingly relied upon natural gas. In 2023, about 43% of electrical power generation was from natural gas. A disruption in the natural gas system could conceivably impact both the supply of natural gas and electricity to our home. While we have never experienced a loss of natural gas to date, the possibility always exists of a terrorist or cyber attack on our natural gas infrastructure. Natural gas and electrical power are no longer independent sources of energy.

3. Load Analysis

A load analysis predicts how much electrical energy is consumed (kWh) over a period of time as well as predicts the peak load (kW). These numbers are compared against estimates of the amount of electrical energy that will be produced by the solar array to estimate the total electrical bill and the total savings possible. The peak load is compared against the power rating of the energy storage (if it exists) to ensure the energy storage can supply the power when off grid.

Over the period 7/6/2024 to 7/7/2025, our solar installation produced 13,277 kWh. Our installation has 28 panels, each rated for 405 watts (a total of 11.34 kW). Thus for each watt of rated panel power, 1.17 kWh of energy was produced in a year (each panel produced 474 kWh on average over a year).

Our solar proposal estimated we would produce 14,000 kWh which was about 5% too high. The unusual weather during this time period could easily explain the difference.

Annual consumption can be estimated from utility bills. For the period 7/6/2024 to 7/7/2025, we consumed 15,480 kWh. Note that this figure includes charging of our PHEVs. Subtracting the energy produced by the solar installation, we purchased 2,203 kWh; We produced about 86% of the electrical energy we consumed.

We currently pay a base fee of $8.14 a month plus $0.14 a kWh (was $0.1326 in 2024). Hence the annual amount we pay for electricity can be estimated as $8.14 x 12 + $0.14 x 2203 = $406.10.

We also received payments of $308.19 for the sale of SRECs. Subtracting this amount from the annual payment results in $97.91 for the year ($8.16 per month).

The peak load is more difficult to estimate with precision. There are a few ways to do so:

a: Demand Load. Prior to switching to Net Metering, our electric bill had a line for "Demand" with a number in kW. This reflects the highest power demand averaged over a 30 minute time period. The highest Demand over a year is a lower bound for the peak load.

b. Usage Data. Since we have a "smart meter", our usage data is available on the Dominion Energy website. Under the usage tab, you can download a spreadsheet with the average power usage over 30 minute increments since the smart meter was installed. From this spreadsheet, our highest 30 minute average was 10.4 kW. The actual peak load is likely somewhat larger than this value.

c. Bottoms Up Estimate. Here one tries to estimate the peak power demand of the largest loads (assuming they are all on at the same time) and add on a base load representative when the largest loads are not online. If the peak demand is not available from the utility, this is about the only way to do it.

4. Design considerations

The previous sections detailed some of the basic design considerations. This section will provide additional nuances in the design of the solar installation.

4.1 Number of solar panels and their arrangement

Short answer is to install as many panels as you can that would have clear exposure to the sun. Ideally the panels would face South and not be obscured by trees; in reality you have to live with how your house is situated on the lot. In arranging the solar panels on the roof, one has to account for obstructions like plumbing vents, bathroom exhaust fan vents, and attic fan vents. If an attic fan or exhaust fan vent is in a bad location, you may be able to move it a bit when replacing the roof (if you need to replace the roof). The solar installers stated that one could cut down a plumbing vent and install a panel over it; I wasn't too keen on doing this. Since our panels are on the front of the house, we only had one plumbing vent on the garage roof to work around; a way was found to arrange the panels without resorting to cutting the plumbing vent and covering it with a panel.

The building code does require a clear area around the panels so maintenance can be performed on them; the building code requires a minimum distance between the edge of the panel and the edge of the roof.

4.2 Rating of solar panels and inverters

The 28 solar panels in our installation have a combined power rating of 11.34 kW. The installation has never produced 11.34 kW; the peak has been around 9 kW. The lower production number is largely because of two reasons. First, the panel rating is based on ideal conditions in the laboratory; in reality the sun is never perpendicular to the solar array when at peak intensity and when the array is sparkly clean from a nice rain shower. And second, the dedicated inverter for each solar panel is only rated for 325 Watts as compared to the panel power rating of 405 Watts. At 325 watts per panel, the maximum amount of power the 28 inverters can provide is 9.1 kW, consistent with the peak power produced. Ideally, one would account for the first reason in determining the rating of the inverters. An inverter with a higher power rating could possibly extract a little bit more power at high noon, but at greater expense. Furthermore, the inverter with a higher rating would likely have lower conversion efficiency at lower power levels; an inverter with a higher power rating may be able to provide a higher peak power, but due to the lower efficiency at lower powers, deliver less energy.

4.3 Load shedding

When off-grid, the battery will be able to provide power longer if power consumption is reduced. There are generally three ways this is done:

a. Manually: the user turns loads off either at the load, or by turning of breakers in the breaker panel box.
b. Separate backup panel: A second power panel is installed that only has a few critical loads on it (refrigerator, sump pump, some lighting circuits, etc). On loss of grid, only the backup panel is provided power.
c. Load shed control of individual loads: Automatic load shed switches are provided for a few (typically 4) large loads. One can decide which of the few loads are shed on loss of power. This is what our system implements. Our four loads that can be shed are: Two EV level 2 charger outlets, the stove/oven, and the clothes dryer. Many people would include the air conditioner compressor in load shedding, but we elected not to. I have configured our system not to shed the stove/oven; having to reset the clock on it after each short duration power outage was becoming a pain. With control of individual loads, I can always restore power to one of the shed loads when off-grid with the system having sufficient power capacity.

4.4 Impact of HVAC on energy storage power rating

The two biggest motors in most houses are the air conditioner compressor motor and the Heating Ventilation and Air Conditioning (HVAC) circulating fan. If these motors do not have a variable speed drive on them, they can draw a large inrush current when they start. If these loads are not shed when off-grid, then one has to make sure that the battery inverters are capable of providing the inrush current. The peak inrush current is listed as LRA (Locked Rotor Amps) on the data label for the motor. The energy storage will list a peak power (typically for 3 seconds). Multiply the peak power by the number of battery units in the system, then subtract off the load (not counting the motor) you expect to have to provide power for when off-grid. Divide this number by 240 volts to get the peak current that can be used to start the motor. If this number is bigger than the LRA, all is ok; if not, then may want to add another battery unit.

In early 2024, our air conditioner had a two-stage compressor and a variable speed drive on the circulating fan. The LRA for the compressor motor was 72 amps. Each of the three batteries has a peak output power of 7.68 kW (3 seconds) and I anticipated the maximum continuous power without the AC compressor to be no more than 6 kW (This is after load shedding the other large loads). 7.68 x 3 – 6 = 17 kW. 17 kW / 240 V = 71 amps which is close enough to 72 amps for me. In reality, most of the time the maximum continuous power without the AC compressor will be well under 6 kW. Furthermore, with a two-stage compressor, the in-rush current for the first stage is probably less than the posted LRA; and the switch from the first stage to the second stage would also result in a smaller in-rush current. Unfortunately, the literature provided by Carrier doesn't provide this insight.

Since we installed the solar power system, we replaced our air conditioner and furnace. Now, both the compressor motor and the circulating fan motor have variable speed drives. One of many advantages of variable speed drives is that they eliminate the large inrush currents. Hence the LRA is no longer an issue.

Also, if you plan on shedding the air conditioner when off grid, this is not an issue either.

4.5 Generator integration

In early 2024, the ability of the solar installations to integrate generators was not ideal. The options were:

a. When the battery ran out of energy, the generator would kick in and power the system; the solar installation would turn off.
b. When the battery state of charge was low, the generator would come on line, recharge the battery while supplying the load, then turn off.

I also would have preferred to have the ability for the generator to automatically come online if the load exceeded a percentage of the rating of the battery power rating; this would prevent overloading of the battery. Unfortunately, none of the available systems had this capability.

The system we have uses option b.

One annoying part of our generator integration is that our generator is tested twice a week instead of once. The generator itself has a test schedule that cannot be turned off. Additionally, the solar installation controller initiates a test to ensure its control signals are working properly. I would prefer to have only the latter test, but can't turn off the generator self-test.

4.6 Panels, disconnect switches, and other hardware.

Depending on the system, you may need to replace your main circuit breaker panel, or add an additional panel. The solar installation required 4 slots in our breaker panel plus another 4 slots for the EV level 2 charger outlets. Our old panel did not have this many open slots. We could have added a second sub-panel. I elected to replace the panel instead of installing a second sub-panel because the circuit breakers were nearly 40 years old and probably should be replaced to ensure reliability. We also have extra slots for future growth.

The batteries and control boxes (see Figure 5) require a bit of wall space. Ours are mounted in the garage. Note that most of the boxes are mounted high to keep them from being damaged should a car drive into the wall. I also ran an ethernet connection back to our network switch; the system could communicate over WIFI, but the hardwire connection should be more reliable. Figure 6 shows the emergency disconnect switch mounted on the backside of the garage. There is also another box mounted near our power meter on the outside of the house that includes the load shed contactors.

Figure 5: Solar Installation equipment inside garage

Figure 6: Emergency Disconnect Switch on back of garage

4.7 Vehicle-to-home (V2H)

An interesting technology that is evolving is vehicle-to-home (V2H). With a special level 2 charger, compatibility with the solar system controller, and with a V2H enabled electric vehicle (EV), one should be able to use the battery of the EV (when it is connected) as part of the overall solar installation. This could be very useful when operating off grid; most EVs have sufficient energy storage to power a home for several days. Integration of EV energy storage with the solar panels along with favorable weather conditions could enable continuous operation off-grid over extended periods of time. In 2025, the technology, standards, and government regulations are all immature; very view cars, chargers, and solar system controllers support V2H. It’s not clear how to ensure compatibility among equipment and EVs that do support V2H.

5. Points of Contact

I worked with three different companies. From what I could tell, all three would have provided an acceptable product. My final choice was based on the best match of technical performance to our particular needs. The price quotes from all three were similar.

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