The “Duck Curve” – What it is – Why You Care

The intent here is a simplified explanation of how and why our patterns of electrical usage create issues for utilities, how rooftop solar impacts those issues, and how energy storage helps solve them. Think “Duck Curve for Dummies”.

Two important facts about electricity are important to the explanation. First, electricity must be used as it is generated. A limited amount can be stored in batteries but it cannot be compressed or liquefied like natural gas or collected in large tanks like water. Second, over half of the electricity generated by power plants is lost during transmission to the homes and businesses where it is ultimately used. Producing electricity on-site eliminates this transmission loss and is therefore more efficient.

Demand Pattern for Electricity

The demand for electricity varies during the day and that variation can be illustrated using a simple chart. In the graphic below, the horizontal (x) axis is a timeline for a 24-hour period and the vertical (y) axis represents the amount of electricity consumed by a home or group of homes during that period. The metric for the y-axis represents amount of electricity consumed, measured in watts. Depending on the number of households represented, the y-axis may be in watts, kilowatts, megawatts, terawatts, etc. but since it is a ratio of usage over time, the shape of the curve illustrates that pattern of demand.

Demand Curve for a typical home (Chart 1)

As you would imagine, the electrical load is pretty low at midnight, rises to a morning peak between 6 and 9 AM when the house wakes up, starts turning on lights and beginning daily activities. Usage goes down later in the morning and well into the afternoon as the family is off to the activities of the day. Generally it begins rising again in mid afternoon when school is out and continues to rise into the evening. Dinner preparation, lights, TVs, and many other electrical draws raise electric consumption to its daily peak between 6 and 9 PM and then it goes down later in the evening and into the night. In areas where air conditioning is common there will be an additional load from early afternoon through the dinner hour, at least in the warmer months.

Demand Curve for two similar homes (Chart 2)
In this demand curve we have added a second, similar home. Notice that because the peaks come at similar times, when you add the electrical load for the second home, the impact at the peaks is magnified and the combined curve becomes slightly more severe.

Demand Curve for thousands of homes (Chart 3)

Because the peaks grow faster than the valleys, the demand curve for large numbers of households with relatively similar electrical usage becomes even more dramatic with higher peaks and more severe slopes.

When you add rooftop solar to some of the homes (Chart 4)
Rooftop solar generates electricity from mid morning to late afternoon, and the amount generated across those hours produces a bell curve of available electricity.

The result is that the electricity provided by rooftop solar decreases demand from the utility (Chart 5).

This locally generated electricity reduces the load required from the utility, in the shape of an upside down bell curve.

Resulting in a steep drop in demand followed by an even steeper rise (Chart 6).
The combination of decreased demand coupled with an increasing supply dramatically increases the slope of the drop in early afternoon and the subsequent rise as demand ramps up while solar supply diminishes.

Hence the name – The Duck Curve (Chart 7)

Resulting Problems
If we could store the electricity in an elevated tank like we use to store water, or under pressure like we store natural gas, we could moderate fluctuating demand through the 24-hour cycle. However, since electricity must be used as it is produced and produced as needed, the large swings in demand, and the bell curve of supply from rooftop solar combine to create three issues that need to be addressed.

**Issue #1: Peak renewable supply (the swayed back of the duck)**

As we continue to add rooftop solar (absolutely the right thing to do) the lowest point of demand for utility supplied electricity drops so low that the utility needs to reduce generation to levels that force them to turn down and even shut down some power plants and/or export electricity.

It takes time to turn down or shut down plants and even more time to ramp up or restart plants, leading to issue number two.

**Issue #2: The steep increase in demand from late afternoon into the evening (the nearly vertical neck of the duck)**

Mid afternoon is the lowest point of electricity demand from utilities. Beginning in late afternoon, the decline in production from rooftop solar, in combination with increasing electrical usage into the evening, results in an exponential rise in electrical demand from the lowest level to what will be the highest level in just a few hours. That ramp up is extremely difficult for utilities to manage.

Unfortunately, the power plants that can be brought online or ramped up faster are the ones that produce electricity by burning fossil fuels.

**Issue #3: Peak demand (the top of the duck’s head)**

The PM Peak that occurs is generally the maximum demand that a utility gets during a 24-hour period. The taller the head of the Duck (peak power required from utilities), the more power plants have to be available and operational. This peak demand is nearly always in the early evening when rooftop solar is not generating and providing any electricity.

As a result, in order to meet peak demand, many utilities are being forced to construct new fossil fuel driven power plants that are only operating a few hours a day, if at all. This is drives up costs and increases the carbon footprint of electrical generation.
Simple Solution – Onsite Energy Storage

The problems we need to address are: 1. Raise the duck’s swayback, 2. Reduce the slope of the late afternoon and evening ramp up, and 3. Lower the peak demand. Onsite energy storage can mitigate all three.

There are two types of onsite energy storage: Electrical energy storage, (typically achieved with batteries like Tesla’s Powerwall), and thermal energy storage. Thermal energy can be stored by the house itself (thermal mass of the structure and contents… including the air) and in the hot water of a heat pump water heater.

- Raising the swayback, reducing the slope of the neck, and lowering the peak demand (Chart 8)

Looking at the red dotted lines you can see that the duck’s back on right is higher and the PM peak on the right is lower. Fully charging home batteries and the batteries in electric vehicles (EVs) in the middle of the day, using energy from the local rooftop solar, raises the swayback by putting less of that excess electricity back onto the grid. That stored energy is then available for use in the late afternoon and into the evening, resulting in a slower ramp up of energy usage and a lower peak. This is smart management of electrical energy storage and use. Thermal storage can be used to accomplish the same goals.

Similar to a thermos, a home that is reasonably airtight (does not lose or gain heat through air leaks) and is also well insulated will maintain its indoor temperature for longer periods of time, even when the outdoor temperature is dramatically higher. In the summer when the duck curve is at its most extreme, cooling such a home an extra degree or two, during the middle of the day utilizes electrical energy from rooftop solar and stores it in the thermal mass, including the indoor air, of the home. Running the air conditioning equipment during mid-day takes advantage of the local rooftop solar and raises the swayback. Later in the afternoon, that cooler temperature stored in the home will reduce the power needed to maintain a comfortable temperature on into the evening. Essentially, functioning as a thermal battery, it reduces the slope of the ramp up and lowers the eventual peak.

Electric heat pump water heaters (HPWHs) are becoming the standard for high performance homes and can also be used to help mitigate the problems illustrated by the duck curve. HPWHs are three times as efficient as traditional water heaters, and very well insulated. They can be programmed to heat the full tank of hot water to the maximum temperature (170 degrees) during the peak solar output hours. The heated water will retain sufficient heat for evening and morning cooking and showers. So the swayback is raised by heating the water in the early afternoon, and the energy needed to replenish hot water is delayed and minimized, thus reducing the slope of the ramp up and lowering the peak.

A Final Word
The Duck Curve illustrates a very real issue that must be mitigated as we transition to an all-renewable future. On site energy storage (electric and thermal) will play an important role in that resolution.

A more fundamental issue to be addressed is the overall demand for electricity. That demand grew exponentially for decades with little concern for efficiency in production, distribution, or usage. Now that we know the environmental costs associated with burning fossil fuels, our energy priorities have evolved to include minimizing waste and maximizing efficiency.

The same strategies and tactics that enable a home to store thermal energy and positively impact the Duck Curve, also make the home significantly more energy efficient, comfortable, and healthy.

Reducing our energy demand through efficiency, coupled with the shift to renewable sources, are two important keys to addressing climate change in our lifetimes. Electricity produced by rooftop solar, used locally during the day and stored locally for use in the evenings, avoids the 50% transmission loss and replaces twice the amount of energy that would be required from the grid.

Managing the problems illustrated by the Duck Curve is an important step in the transition to an all-renewable, carbon free future. By addressing the issues of the Duck Curve today we are enabling the transition to that future.

Written by Jay Gentry
Images courtesy of Brian Rubin, DimensionStyle Ltd.