How to Compare Power Generation Choices

People like to compare the cost to generate electricity from various renewable resources, like wind or solar, to the cost to generate electricity from coal, nuclear and natural gas. Comparing these costs is like comparing apples to oranges. Power generation is a complex business and without considering capacity factor; capacity (kW) and energy (kWh); and fixed and variable costs, these comparisons are not legitimate for evaluating power generation technologies.

Capacity Factor

Let's begin with Capacity factor, or the percentage of hours that a power plant operates at its maximum capability in a given time period. So, if a 1000 MW nuclear plant has an annual capacity factor of 98%, then that means it is operating at 1000 MW for 98% of the hours in a year.

Power plants can be categorized by capacity factor. Base load power plants typically have annual capacity factors that exceed 75%, but usually are more like 90% to 98%. Power plants that fall into this category can be large (400 MW and larger) fossil fueled plants (coal, natural gas or, less often, fuel oil) as well as nuclear plants. On the renewable resource side, geothermal and biomass plants can be placed in this category. Not many hydro plants in the U. S. fall into this category unless the dam is large or the flow rate on the river is high and the weather cooperates.

Intermediate loaded power plants typically have annual capacity factors ranging from 40% to 60%. Small (100 MW to 300 MW) coal plants may operate at these capacity factors. However, the most common technology that would operate economically in this capacity factor category is the combined cycle combustion turbine, or CCT, fueled by natural gas with fuel oil as a back up source of fuel. Most of the hydroelectric plants in the Western part of the U.S. can operate as intermediate loaded plants providing that the weather cooperates, which means that the western mountain ranges receive an above average amount of snow during the winter months. Offshore wind power will also likely operate in this category of capacity factor. Concentrated solar power, or thermal solar, may break into the low end (40%) of this capacity factor range as will wave energy technology (30% to 45%).

The third capacity factor category is peak load generation, and the power plants in this category usually operate at very low annual capacity factors ranging from 5% to 15%. This means that these types of power plants are operating at their maximum capability for only 5% to 15% of the hours in a year. The most common type of power plant in this category is the combustion turbine (CT), or simple cycle turbine (SC), fueled by natural gas with fuel oil as a back up source of fuel. The next most common type of power plant in this category would be the internal combustion engine (IC) fueled by natural gas.

Renewable resources that would fall into this category are: wind on land; photovoltaic solar; concentrated solar (thermal solar); and tidal current technology. For wind on land, the average annual capacity factor ranges from 20% to 30%. One caveat is: In order for me to be able to place wind on land into the peak generation technology category, I am assuming that the wind is blowing coincident with the utility's peak load. If this is not occurring, but the wind turbines still have the same 20% to 30% capacity factor, then we would have to add energy storage costs to the wind turbine costs for it to be operationally equivalent to any other peak loaded generation technology.

Photovoltaic solar has capacity factors that range from 20% to 25%, while concentrated solar capacity factors vary between 25% and 40%, allowing this resource to linger between a peaking facility and an intermediate facility. The capacity factor for tidal current technology is estimated to average 27%. .

Now that all of the power generation resources are in an appropriate capacity factor category, think of each capacity factor category as a customer need. Then think of the types of power generation technologies within a capacity factor category as the various products that compete to satisfy that particular customer need. This means that it makes no sense at all to compare the cost per kWh to generate electricity from wind on land with the costs per kWh to generate electricity from coal because these two technologies satisfy two different customer needs, namely one is a peaking technology, while the other is a base load technology.

Is there a way to compare technologies from two different capacity factor categories? Yes, but one technology would need to be altered to make it operationally equivalent to the other. In other words, alter one technology so that both are then in the same capacity factor category. To do this for wind on land versus coal, it would be necessary to run the coal plant as a peaking unit, recalculate all of its costs, and compare those new costs to the wind on land power plant costs. The wind on land power plant could also be altered to operate base loaded, recalculate its new costs as a base loaded unit and compare those to a coal plant.

However, before trying these more complicated comparisons, it is necessary to understand the concepts of capacity versus energy.

Capacity versus Energy

In order to learn how to compare technologies within a capacity factor category, one has to understand a number of terms and concepts, like the difference between capacity, measured in kilowatts (kW) or megawatts (MW), and energy, measured in kilowatts-hours (kWh) or megawatt-hours (MWH).

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People often quote costs/kW when they are really talking about costs/kWh. Since these sound similar, they must be similar. Unfortunately, they are not.

Capacity for a power plant (kW or MW) is probably best explained with a highway analogy. A ten-lane highway has the ability to allow more cars to get from one point to another in a given time period when compared to a three-lane highway. Likewise, a 1000 MW power plant has the ability to put more energy, or MWH, to the grid in a given time period than a 500 MW power plant. The size of the highway is analogous to the capacity, or MW rating, of the power plant. The number of cars that pass from one point to another on the highway during a given time period is analogous to the energy, or MWH, that the power plant delivers during the same time period.

So, the more lanes on the highway, the more cars that can pass from one point to another in one hour. Therefore, the larger the capacity of the power plant, the more energy the plant can deliver to the grid in one hour.

Now that we understand the difference between capacity and energy, we can begin to compare the costs of one power plant to another.

Initial Cost Comparison

The cost to build a power plant, or its capital cost, is usually discussed in $/kW of capacity. When you hear that the latest estimate for a brand new nuclear plant is $4,400/kW to $7,700/kW, this means that the cost to build a new 1,000 MW nuclear plant ranges from $4.4 billion ($4,400/kW X 1,000 MW X 1,000 kW/MW) to $7.7 billion ($7,700/kW X 1,000 MW X 1,000 kW/MW).

Note that this has nothing to do with the cost to operate or maintain the plant. It is just the upfront cost to build the plant. This is a quick way to compare which technology is the most expensive or least expensive to build. In general, base load technologies will be more expensive to build than intermediate load technologies, while intermediate load technologies will be more expensive to build than peaking technologies.

Suppose that a utility has a 100 MW customer load that needs to be supplied, but the load is only on the system for three hours per day. The utility needs to build a power plant to supply this load. What should it choose?

First, determine the load factor (similar to capacity factor, but for the load and not the generation). Load factor is: 3 hours / 24 hours = 12.5%, which calls for a peaking power plant. Next, compare the cost to build the various competing peaking power generation technologies. The peaking options are laid out in the table at the top of the next page.

Peaking Technology	Capital Cost
Internal Combustion Engine	$580/kW to $910/kW
Combustion Turbine	$700/kW to $1,075/kW
Pumped Hydro Storage	$2,000/kW to $3,500/kW
Battery Storage	$2,500/kW to $3,000/kW
Wind on Land	$1,600/kW to $2,200/kW
Thin Film Photovoltaic Solar	$3,000/kW to $3,500/kW

Perhaps the utility needs to know a little more about this load. At the very least, the utility needs to answer the following questions.

1. Does this load always run for three hours or can its duration vary?
2. Does the load come on and go off at the same time each day?
3. If yes to question # 2, then determine what time of day the load runs?

Suppose that the load duration does not vary; the load turns on and off at the same time each day; and that time is from 12:00 noon to 3:00 PM. In this case, whatever technology the utility chooses has to be capable of providing capacity and energy from 12:00 noon to 3:00 PM each day.

If the utility narrows its choices for peaking options down to the three least expensive technologies to install, then the concerns related to those peaking technologies need to be addressed. These concerns are summarized in the table at the top of the next page.

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Peaking Technology	Possible Concerns
Internal Combustion Engine	This technology can turn on and off whenever it is needed, and ramps up rapidly from zero load, but…. 1. How much does the fuel cost to run it? 2. How much does it cost to maintain? 3. How much pollution does it exhaust when it does run?
Combustion Turbine	This technology can turn on and off whenever it is needed, and although it ramps up quickly from zero load, it is not as fast to ramp as the Internal Combustion Engine, and…. 1. How much does the fuel cost to run it? 2. How much does it cost to maintain? 3. How much pollution does it exhaust when it does run?
Wind on Land	1. This technology runs when the wind blows. The utility cannot turn it on and off when it is needed, unless the utility combines it with battery storage. 2. How much does it cost to maintain? 3. Does it have some other impact on the environment?

After reviewing the options in the table above, can the utility make a decision? The answer to this question is no. There are at least four concerns related to these technologies that need to be quantified and compared in a fair manner. Those are: fuel costs, pollution costs, operating and maintenance costs and capital costs. The most objective way to compare these four costs across technology choices within a capacity factor category is to divide them by the output of the power plant (kWh), or per unitize them.

Variable versus Fixed Expenses

Before per unitizing these costs, the terms, variable and fixed costs need to be defined. A variable cost is an expense that varies with revenue or the volume of sales. Be careful, most people revert to the dictionary definition of variable when they hear the term variable cost and think it means that it is an expense that varies with time. This is incorrect. In the financial world, a variable expense varies with revenue or volume. A fixed expense is an expense that does not very with revenue or volume. For every expense, you ask and answer a simple question: "If I produce and sell one more kWh do I spend more money on this expense?" If the answer is yes, then it is a variable expense. If the answer is no, then it is a fixed expense.

Fuel costs are driven not only by the cost of the fuel that is being converted to electricity, but also by the efficiency of the conversion process. Fuel costs are truly variable costs. That is, these costs vary directly with the kilowatt-hours (kWh) generated by the plant. When more electricity is produced, more fuel is consumed.

Pollution costs are the cost to purchase pollution credits, like NOx and SO_2 credits. These are market based credits that are a function of the tons of NOx or tons of SO_2 that the plant emits. The amount of NOx or SO_2 that the plant emits is directly proportional to the fuel consumed, which is a variable cost. Therefore, pollution credit costs are also variable costs.

O&M costs, on the other hand, are not generally considered to be variable costs. The plant staff earns a base wage plus benefits that are fixed. Overtime for increased production is an extremely small contribution to variable costs; so small that it is usually disregarded. Similarly, routine and overhaul maintenance are considered fixed costs. Incremental plant operation, unless much more than typical, does not alter the usual maintenance routine and intervals. Finally, many costs associated with the plant, like insurance and property taxes, are fixed and only change with variables outside the plant domain. Both of these costs generally increase yearly with the inflation rate.

Cycling a plant from full output to lower output levels causes an increase in wear and tear on the plant components. Although the money spent on labor and material to operate and maintain the plant does not change at the time the cycling occurs, the increase in wear and tear can increase the frequency of future maintenance, thus causing an increase in average O&M costs. Therefore, O&M costs do not usually increase with each new kWh generated by the plant.

Although this seems like a minor point, it is financially crucial that the individuals making short-term pricing and running decisions for the plant understand this concept. The financial implication is that increasing the plant output by 10% when it is already running does not increase the plant's O&M costs significantly. Therefore, the generation company can maximize profit by accepting a lower price for the incremental kWh that the plant generates as long as the price that the company receives covers the plant's increase in variable costs, which in this case would be the plant's increase in fuel costs and pollution credit costs. In fact, a large portion of the incremental revenue that the generation company realizes from the 10% increase in plant output will be added right to profit if the plant's incremental fuel cost per kWh and pollution credit costs per kWh are small in comparison to the incremental market price that the company charges for the additional kWh.

A company experiences capital costs, namely depreciation and financing costs for the construction of the plant, with the passage of time. Whether the plant produced one kWh or a million kWhs has no impact on the amount of depreciation and interest costs that the plant incurs. Therefore, capital costs are also fixed costs.

So, fuel and pollution credit costs are variable costs, while O&M costs and capital costs are fixed costs.

Cost Per kWh Comparison

Even though some of the cost categories discussed so far do not vary directly with the kWh generated by the plant, it is useful from a competitive analysis point of view to look at all plant costs (fuel, pollution credit, O&M and capital) on a per kWh basis. This is easy to do for fuel and pollution credit costs since they do vary directly with the kWh output of the plant.

For O&M costs, however, take the total amount spent on O&M over a one to three year period and divide that number by the kWh produced during that time period. This will provide an average O&M cost per kWh. Obtaining the capital costs in a $ / kWh form will require a few assumptions.

Although equity requirements can be a large percentage of any project today, for the ease of explanation let's assume 100% project financing (a form of bank financing).

To obtain the capital costs in a $ / kWh form, we must annualize the total cost of the plant and then divide that annual cost by an estimate of the average annual kWh that the plant is expected to produce. The following formula is used to calculate the annual cost of a plant.

$$\text{Annual Cost} = \frac{(\text{Annual Interest Rate}) \text{ X } (\text{Total Cost of the Plant})}{1 \quad - \quad \dfrac{1}{(1+\text{Annual Interest Rate})^{n}}}$$

Where n = number of years over which the plant is expected to be financed.

Suppose that there is a series of wind turbines that total 200 MW of capacity. Assume that these wind plants cost $2,000/kW to install or $2,000/kW X 200 MW X 1,000 kW/MW = $400,000,000 total. Assuming an annual cost of financing of 10% or 0.10 and a loan term of 20 years, calculate the annual cost of this wind farm using the formula above.

$$\text{Annual Cost} = \frac{(0.10) \text{ X } \$400{,}000{,}000}{1 \quad - \quad \dfrac{1}{(1 + 0.10)^{20}}} = \$46{,}983{,}850$$

Next, estimate the average annual kWh output of the plant. A generous estimate would be to assume that the plant would operate at an average annual capacity factor of 30% over its life. This means that it would be running at rated capacity for 30% of the hours each year. This would amount to 0.30 X 24 hrs/day X 365 days/ year or 2,628 hours/year. At this load factor it would generate 200 MW X 1,000 kW/MW X 2,628 hours = 525,600,000 kWh/year.

Thus, for the 200 MW wind farm, the estimate for its annual capital cost/kWh would be: $46,983,850 / 525,600,000 kWh = $0.0894 / kWh or approximately $0.09 / kWh. One can follow this same procedure for any type of power plant.

Now that all of the relevant costs/kWh for a power plant can be obtained, let us look at all of the costs/kWh for two of the peaking technologies. Those costs are summarized in the table at the top of the next page.

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Plant	Cost per kWh	Initial Installation cost per kW
Combustion Turbine (CT)	Fuel $0.068 - $0.109 NOx $0.000 - $0.000 O&M $0.010 - $0.014 Capital $0.062 - $0.096 Total $0.140 - $0.219	$700/kW to $1,075/kW
Wind on Land	Fuel $0.000 - $0.000 NOx $0.000 - $0.000 O&M $0.001 - $0.002 Capital $0.071 - $0.098 Total $0.072 - $0.100	$1,600/kW to $2,200/kW

Assume that all of the other choices for peaking power except for the combustion turbine and wind on land have been eliminated. At first glance, it appears that wind on land is the clear winner. But is it?

All this table shows is what the power plant's total cost per kWh will be if it operates at a 30% capacity factor. Now compare this total cost per kWh to what you think a reasonable market price would be. You want the total cost per kWh to be lower than a reasonable market price. Once you know that each technology can be profitable, you need to go one step further and consider the risks that are involved with each choice.

The risk that the utility is taking in choosing the wind plant is weather risk. If the wind does not blow coincident with the utility's peak demand, then this plant is useless. Note that the total costs/kWh for the combustion turbine are double compared to the total costs per kWh for the wind on land plant. The utility pays a premium for the combustion turbine because it is available 24 hours per day.

If, by looking at all of the costs/kWh there is still no definitive answer for which technology is best, then why go through all of these calculations? Having these costs/kWh for all of the technologies that a company is considering helps it to organize and recognize the risks associated with each type of power plant. In other words, in this form, the utility can quickly see how sensitive each technology's total costs are to changes in fuel costs; changes in the cost of pollution credits; changes in O&M costs; and changes in capacity factor or capital costs. This exercise allows the company to identify those technologies that it wants to consider for its final analysis, the capital investment analysis.

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The company then chooses to perform a capital investment analysis on the technologies that have a reasonable chance of being cost competitive in their respective capacity factor market and which have risks that the company feels comfortable managing. In this final analysis, you perform a 10, 15, 20 or 30-year net present value analysis on the cash flows for the construction and operation of each relevant technology. The technology that has the highest probability of maintaining a positive net present value over the analysis period and under various changes in cost and operating assumptions is the one the company should select.

In the end, when it comes to comparing the costs of generation technologies, don't automatically believe everything you hear or read. A legitimate comparison of generation technologies takes into account capacity factor, identifies risks associated with the costs/kWh for each technology, and then performs a net present value analysis on those technologies with risks that the company feels comfortable managing. This is the only legitimate way to evaluate power generation technologies.