A Functional Replacement of Combined Cycle Combustion Turbine using Renewable Energy and Batteries

January 2020

Summary of Year One $/MWH of functionally equivalent resource projects

Shown below is an apples-to-apples comparison of year 1 costs for functionally equivalent projects on a dollar per kilowatt-hour basis at varying fuel price levels. The goal was to develop reasonable replacement resources of Clark Public Utilities' River Road Combined Cycle Natural Gas Combustion Turbine generation plant. The four plants below perform in similar planning function as RRGP. This table takes into account all capital, annual, variable, and fuel costs. Keep in mind the current retail rate for Clark Public Utilities is $0.0816 per kilowatt-hour.

	Year One Cost based upon natural gas price delivered to RRGP ($/KWh)								
Gas Price ($/MMBtu)	$ 2.00	$ 3.00	$ 4.00	$ 5.00	$ 6.00	$ 7.00	$ 8.00	$ 9.00	$ 10.00
Combined Cycle Combustion Turbine	$0.02425	$0.03025	$0.03625	$0.04225	$0.04825	$0.05425	$0.06025	$0.06625	$0.07225
Solar Plant based upon Annual Capacity Factor - All Winter Storage	$10.93	$10.93	$10.93	$10.93	$10.93	$10.93	$10.93	$10.93	$10.93
Solar Plant based upon December Monthly Capacity Factor	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21
Wind Plant based upon Annual Capacity Factor - 400 hours of battery	$1.86	$1.86	$1.86	$1.86	$1.86	$1.86	$1.86	$1.86	$1.86

Genesis and Background

During the September 23rd Clark Public Utilities (CPU) Power Supply Workshop, Commissioners asked the question, "how much would it cost to replace CPU's River Road Generating plant with a combination of renewable energy and batteries to make the two functionally equivalent"?

RRGP is CPU's 248 MW nameplate Combined Cycle Combustion Turbine (CCCT) that burns natural gas to produce electricity. On a planning basis, RRGP supplies CPU with ~42% of its average electricity consumption. CPU may run the plant as planned or it may find power supply less expensive in the market compared to buying gas and converting it to energy. However, there are no guarantees of these opportunities occurring. Thus, for the purposes of this comparison, the basis for functionality will be planning purposes only.

RRGP is 25 years-old. With an excellent maintenance and performance record, RRGP could operate at least another 25 years. Like most long-tenured one owner assets, the original mortgage on RRGP is almost paid. There will always be large on-going capital costs for parts replacements, but CPU forecasts these as small and fairly spread out over time. Thus, the fixed payments reduce significantly meaning only the cost of fuel and variable maintenance remains. Comparing RRGP to brand new renewable and batteries with their high upfront capital costs would be unfair. To make this a true apples-to-apples comparison, a new CCCT with its up-front capital costs should be the basis for comparison to the renewables and batteries combination when examining the economics.

The planned generation output for the new CCCT will use RRGP planning output as the basis for this comparison. The next section outlines the assumptions for physical production as planned to meet CPU requirements in operations and contractual obligations.

Output Assumptions

CPU's Power Supply Contract (PSC) with the Bonneville Power Administration (BPA) requires CPU to bring the supply associated with RRGP to its load in the following manner for every year starting 2012 and beyond. This table excerpted from Exhibit A of CPU's PSC with BPA.

(C) Specified Resource Amounts

Specified Resource Amounts													
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**annual aMW**
Fiscal Year 2012													
Total (MWh)	178,560	173,040	178,560	178,560	167,040	178,320	172,800	81,840	158,400	167,400	167,400	172,800	224.809
HLH (MWh)	99,840	96,000	99,840	96,000	96,000	103,680	96,000	45,760	91,520	90,000	97,200	92,160	224.756
LLH (MWh)	78,720	77,040	78,720	82,560	71,040	74,640	76,800	36,080	66,880	77,400	70,200	80,640	224.876
Peak (MW)													N/A

Spreading the MWH amounts across each hour of the Heavy Load Hours (HLH) and Light Load Hours (LLH), the amounts come to the following averages.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Hourly Average MW	240	240	240	240	240	240	240	110	220	225	225	240
HLH Average MW	240	240	240	240	240	240	240	110	220	225	225	240
LLH Average MW	240	240	240	240	240	240	240	110	220	225	225	240

These numbers do not comport exactly to actual production expected but for the purposes of this analysis, they are sufficient.

Common Assumptions for Resources/Transmission

Budget and time constraints warrant a simplified set of assumptions.

- No land requirements for generation siting considered.
- No power transmission or gas transportation issues considered
- No losses assumed including the round trip losses of battery storage
- Plant life of 30 Years. Battery lifecycle projected at 15 years due to cycling and parasitic losses. Assume year 16 battery capital costs are half the current price.

- 4% cost of capital for all upfront costs, life of loan 30 Years.
- No Investment Tax Credits or Production tax credits for renewables
- Construction and Permitting time requirements set to zero. Plants commercial operation dates are Jan 1, 2020.
- Average Wind and Solar production every year
- Use Year 1 cost results for comparison
- Analysis is for planning purposes, no unplanned outages or forced outage rates assumed.
- Lifecycle and environmental impacts of mineral extraction, chemical disposal, and air quality are considered to be addressed through local rules and regulations
- Social cost of carbon not included in base calculations but will be discussed separately
- Perfect knowledge of storage and discharge of batteries to mimic planning need

Proxy Plant Data

For cost data of the proxy plants, the Northwest Power Planning Council's (Council) reference plant data from the Generating Resources Advisory Committee is sufficient. Industry experts vet and accept these numbers.[1]

CCCT Data

Shown below is the most recent reference draft plant data from the Council.

2021 Plan Reference Plant: CCCT

Configuration & Technology	1x1 General Electric 7HA.02 Frame, Dry-cooling, Single Fuel
Capacity (MW)	573 MW (ISO)
Heat Rate HHV (Btu/kWh)	5973 (ISO)
Location	East-side
Financial Sponsor	IOU
Economic Life (years)	30
Overnight Capital Cost ($/kW)	$1,150
Fixed O&M Cost ($/kW-yr)	$10
Variable O&M Cost ($/MWh)	$3
Development Time (years)	2
Construction Time (years)	2
Earliest Commercial Online Date	2021
Potential	

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[1] https://www.nwcouncil.org/energy/energy-advisory-committees/generating-resources-advisory-committee

The analysis will prorate to the MWs discussed above. The location is on the east side of the mountains, indicating the difficulty of getting new plants sited in the I-5 corridor.

Solar Plant Data

To take full advantage of solar availability, use the east side draft solar plant referenced by the Council below.

2021 Plan Reference Plant: Solar PV

	Solar PV - Western Washington	Solar PV - East of Cascades
Configuration	15 MW_{AC} mono PERC c-SI with single axis tracker	100 MW_{AC} mono PERC c-SI with single axis tracker
Location	West of the Cascades in Washington State	Areas with high solar irradiance in ID & MT, Southern OR, and East of the Cascades in OR & WA
Technology Vintage	2019	2019
Development Period (Years)	1	1
Construction Period (Years)	1	1
Capacity (MW)	15	100
Inverter Loading Ratio (DC:AC Ratio)	1.4:1	1.4:1
Capacity Factor	24.7%	32.5%
Overnight Capital Cost ($/kW)	1,465	1,350
Fixed O&M Cost ($/kW-yr)	14.55	14.55
Variable O&M ($/MWh)	0	0
Economic Life (years)	30	30
Financial Sponsor	IPP	IPP
Transmission	PSE NT	TBD
Max Build Out	TBD	10,000 MW+ (Exact # TBD)

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Wind Plant Data

Use Montana as it is most favorable to overall production

2021 Plan Reference Plant: Wind

	Onshore Wind - Columbia Gorge	Onshore Wind - SE Washington	Onshore Wind - Montana
Configuration	60 x 3.6 MW, 105 meter hub height	60 x 3.6 MW, 105 meter hub height	60 x 3.6 MW, 105 meter hub height
Location	OR/WA	WA	MT
Technology Vintage	2019	2019	2019
Development Period (Years)	2	2	2
Construction Period (Years)	1	1	1
Capacity (MW)	216	216	216
Capacity Factor (%)	39.8%	41.2%	45.5%
Overnight Capital Cost ($/kW)	1,450	1,450	1,450
Fixed O&M Cost ($/kW-yr)	30	30	30
Variable O&M ($/MWh)	0	0	0
Economic Life (years)	25	25	25
Financial Sponsor	IPP	IPP	IPP
Transmission	BPA P2P	BPA P2P	PSE CTS + MT Int + BPA P2P
Max Build Out	TBD, substantial	TBD, substantial	TBD, substantial

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Battery Data

2021 Plan Reference Plant: Battery Storage

	Standalone Battery Storage - Four Hour
Configuration	100 MW, 400 MWh Lithium Ion Battery Storage
Capacity (MW)	100
Energy (MWh)	400
Round Trip Efficiency	88%
Financial Sponsor	IOU
Economic Life (years)	15
Overnight Capital Cost ($/kW)	1400
Fixed O&M Cost ($/kW-yr)	31

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Setting up functionally equivalent combinations of renewable plus batteries to mimic a CCCT.

There are two ways to calculate deterministically a combination of renewables plus batteries to mimic the production of a CCCT.

1. Using the annual capacity factor of the renewable resource to determine the minimum size of the renewable build needed to produce enough electricity across the year to equal the CCCT's annual production. Then use batteries to shape the renewable production either hourly, daily, or seasonally to meet the hourly requirements expected from the CCCT production.
2. Using the worst-case monthly capacity factor to determine the minimum size of renewable build to meet the worst-case electricity production for any month of the year. By definition, this ensures the renewable resource produces enough electricity in all months. Then, use batteries to shape the electricity in that worst case month to handle the nighttime hours. This method will produce copious amounts of surplus energy in the other months, presumably for resale, however for the purposes of this analyses no value is included for this surplus. This is a cost-based analyses.

The proxy plant data provides annual capacity factors for our renewable plants. The monthly capacity factors are a bit more difficult to ascertain, but reasonable representations are possible.

Calculate renewable capability needed to produce annual equivalent amount of RRGP energy

To calculate the capacity needed to product the energy that RRGP produces each year requires the annual capacity factor of the renewable resources. For the CCCT it is simple. To produce the hourly equivalent max energy as RRGP, the CCCT must be 240 MW or larger.

Solar capability needed based upon annual capacity factor.

The annual capacity factor of the designated solar plant is 32.5%. The hourly average energy produced by RRGP is 224.8 MW. To determine the least amount of solar capability needed, using average weather, divide 224.8/.325 = 692 MW of solar machine capability needed to produce the same about of energy in a year as the RRGP. At $1,350,000 per MW, the capital cost is $934 Million. Note that using west side solar would increase the project costs by $400 Million.

Wind capability needed based upon annual capacity factor.

The annual capacity factor of the designated wind plant is 45.5%. The hourly average energy produced by RRGP is 224.8 MW. To determine the least amount of wind capability needed, using average weather, divide 224.8/.459 = 494 MW of wind machine capability needed to produce the same about of energy in a year as the RRGP. At $1,450,000 per MW, the capital cost is $716 Million. Note that using Gorge wind would increase the project costs by $108 Million.

Calculate capability needed to produce monthly equivalent amount of RRGP energy in the month of lowest available renewable resource.

Solar capability needed based upon lowest monthly capacity factor.

To find the month that has the least amount of sun available to produce electricity is not hard. In the Pacific Northwest, it is either December or January.

The table below represents the average monthly weather data for a station at Moses Lake, WA[2], a town along I-90 on the east side of the Cascade mountains. This is a pretty fair representation of a location where a solar PV farm may be located to take full advantage of sun and high voltage transmission. The column that is of most interest regarding solar power is the last column on the right. The solar radiation total for the month is a reasonable representation of the amount of solar energy that available for PV generation in the month, on average.

[2] http://weather.wsu.edu/index.php?p=93150

Monthly Averages for Period of Record					
Date	Avg Air Temperature			Tot Prec in	Total Solar Rad MJ/m²
	Min °F	Avg °F	Max °F		
January 01, 2009 - December 31, 2019					
January	25.7	30.9	36.8	0.80	123
February	26.8	34.6	43.6	0.53	226
March	32.3	43.1	54.5	0.62	406
April	38.8	51.3	63.4	0.52	580
May	46.2	60.5	73.5	0.57	738
June	52.0	66.3	79.6	0.62	792
July	56.6	73.6	89.0	0.13	853
August	55.9	72.1	88.0	0.15	705
September	47.8	62.5	77.8	0.22	509
October	38.6	49.9	62.4	0.71	313
November	30.2	38.1	46.9	0.68	160
December	23.3	29.4	35.5	0.83	110

Note that the solar availability in July is 7.5 times that available in December. Given the tilt in earth's axis and the resulting differing angles of sunlight and the differing number hours of sunlight this explains a large portion of the difference. The shape of precipitation across the year and the fact that some of that precipitation in winter is snow completes the picture.

To calculate the monthly capacity factors for electricity production from solar, the solar radiance is a reasonable starting point. By computing the solar radiance each month as a percentage of the annual average solar radiance then multiplying by the annual capacity factor, a reasonable monthly capacity factor results for each month. See the following table.

Month	Monthly total solar radiance (MJ/m^2)	% of average annual Solar Radiance	Normalize to annual capacity factor (*.325) to approximate Monthly Capacity Factor (%)
January	123	27%	9%
February	226	49%	16%
March	406	88%	29%
April	580	126%	41%
May	738	161%	52%
June	792	172%	56%
July	853	186%	60%
August	705	153%	50%
September	509	111%	36%
October	313	68%	22%
November	160	35%	11%
December	110	24%	8%
Average for Year	**459.6**	**100%**	**32.5%**

December is the lowest monthly capacity factor. As we expect 240 average MW-hours per hour from the CCCT in December, the amount of solar capability needed to produce that same amount of electricity is 240/.08 = 3000 MW of Solar PV. At $1,350,000 per MW the capital cost equals $4.5 Billion. While this is much more than the capital needed for the solar PV based upon the annual capacity factor, battery storage requirements remain the same for this analysis.

To put the 3000 MW of solar capability into perspective, consider the state of California. Between rooftop and utility scale solar, the total solar capability for California totals over 11,200 Megawatts and represents roughly 30% of all solar capability currently in the United States[3]. The total number of households in California is roughly 11.5 Million[4]. This equates to roughly 1 Kilowatt per household. Clark County contains roughly 127,000 households[5]. If Clark County were to have the same ratio or Solar MW-to-# of Households as California, the installed solar capability would be approximately 127 MW, considerably less than the 3000 MW needed to produce the equivalent energy output of the CCCT.

Wind capability needed based upon lowest monthly capacity factor.

A similar analysis for wind as done for solar is not necessary. Using the historical data gathered from our participation in Columbia gorge wind production, the

[3] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_02_b
[4] http://www.census-charts.com/HF/California.html
[5] http://www.census-charts.com/HF/Washington.html

wind generation across the months are fairly evenly distributed, save a little more in the spring than other months. Thus, the amount of wind capability for the year suffices as a proxy for any given month. This could use further study, but for this analysis, this assumption suffices.

Energy production is only part of the equation when comparing renewables to baseload generation. While the amount of machine capability calculated above for solar and wind may replace the energy produced by RRGP, over a month or a year, the production is wildly intermittent and variable. That is where the use of batteries becomes important. Discussion of the battery component follows in the next section.

How many batteries needed?

Without a means to store electricity produced by renewable generation and then discharge later, no amount of solar or wind machine capability can meet the planning requirements of continuous generation that a CCCT can. Batteries are a natural fit for this type of need.

From a commercial perspective, batteries of the size and duration required for this type of shaping are in their infancy stage. Looking to California again for example, as of March 2019 there was approximately 230 MW of battery storage capability in the whole state.[6] This is not enough battery capability to meet the replacement needed for our CCCT.

While prices have come down appreciably, they are still very expensive when comparing their functionality to generation resources that convert one form of energy into electricity.

There is an energy procurement cost associated with batteries not factored into wind or solar production. Because a CCCT produces energy on demand, one can make a bit of comparison between a battery and CCCT. However, the CCCT does not need to shut down to zero MW to take its energy onboard for production later. Additionally, The CCCT is converting one form of energy to another form, making it a bit more diverse than the battery that requires the same form of energy, electricity, as its form of energy input.

The battery storage proxy used for this analysis demonstrates their costly nature. The capital cost for a 100 MW battery is $1,400,000 per MW. This is for a battery that can only store 4 hours of discharge capability, which is a generous assumption. This cost is in the same range as the actual resources that can produce energy continuously (solar - $1,350,000 per MW, wind - $1,450,000 per MW, and CCCT – $1,150,000 per MW). Batteries are a load on the electric grid and must charge before use.

[6] https://www.eia.gov/todayinenergy/detail.php?id=40072

With the costs of batteries rivaling the generation costs, keeping the size and number of batteries needed to a minimum is paramount in this comparison. For the purposes of this analysis, a combination of batteries that equal 240 MW will be referred to as one battery.

Ideally, it would be great if the configuration only needed one battery. When the wind is not blowing or the sun is not shining, the 240 MW drawn from the battery covers the largest one-hour requirement. However, this combination per our proxy plant specifications could only support four continuous hours of supply when there is no electricity from renewable energy available.

Continuous duration output to cover the hours when the renewable resource is not producing enough to meet the equivalent of the hourly production from the CCCT is a key attribute. The question then becomes what is the least number of Megawatt-hours of storage from a series of 4-hour batteries needed by each renewable resource to reliably mimic the CCCT?

Battery Megawatt hours for solar based upon annual capacity factor?

Given that during the winter in the PNW, it is dark around 16 hours a day, the minimum number of battery combinations could just be four (16 hours divided by a 4 hour battery). This moves the capital costs up to $5,600,000 per MW (4X$1,400,000).

However, the sun does not shine every day in the PNW. On the east side, weather inversions are quite common where there can be a series of days with no sun, especially when snow events are part of the mix. In addition, at times, the accumulation of snow will block the ability of the panels to absorb sunlight. A detailed analysis of a typical December shows the issue.

Note that 7.75 times more solar radiation energy per square meter is available across the month of July than is available in December. Normalizing the production of electricity from solar energy per month to the 692 MW of solar capability calculated to meet our annual energy needs are shown in the table on the next page.

Calculating the hourly average energy available from Solar per month to meet annual energy equivalentto a Combustion Turbine.									
Month	Monthly total solar radiance (MJ/m^2)	% of average annual Solar Radiance	Normalize to annual capacity factor (*.325) to approximate Monthly Capacity Factor (%)	Solar Capacity (MW)	Monthly Average Energy Generation from Solar = Monthly Capacity Factor * Solar Capacity (Hourly Average MW)	Expected Hourly Average Generation	Average Hourly Surplus/ (Deficit)	Hours in Month	MWh Surplus Deficit from Solar Generation
January	123	27%	9%	692	60	240	-180	744	(133,778)
February	226	49%	16%	692	111	240	-129	672	(86,960)
March	406	88%	29%	692	199	240	-41	745	(30,784)
April	580	126%	41%	692	284	240	44	720	31,555
May	738	161%	52%	692	361	110	251	743	186,601
June	792	172%	56%	692	388	220	168	720	120,651
July	853	186%	60%	692	417	225	192	744	143,161
August	705	153%	50%	692	345	225	120	744	89,277
September	509	111%	36%	692	249	240	9	720	6,539
October	313	68%	22%	692	153	240	-87	744	(64,603)
November	160	35%	11%	692	78	240	-162	721	(116,588)
December	110	24%	8%	692	54	240	-186	744	(138,511)
Average for Year	**459.6**	**100%**	**32.5%**		**224.9**	**225.0**	**0**		
A	B	C	D	E	F	G	H	I	J

A letter at the bottom identifies each column. Starting in Column B with the total monthly Solar Radiance on average, a series of calculations from Column C to Column F converts the ratios of monthly radiance into the hourly average MW-hours of electricity produced in each month. The daily amount of electricity from the plant is calculated per day and divided by 24 hours in the day to normalize the data. Of course, the hourly average of electricity is a somewhat misleading as there are hours each day that the solar plant will not be producing when it is dark. However, since the CCCT does produce energy every hour of the day, using hourly average as the unit is way of comparing apples to apples.

Column F represents the average hourly production of electricity by the solar plant for each month of the year. Subtracting this amount from the expected hourly average output from the CCCT produces an hourly average surplus/(deficit) for each month. When that number is positive, the batteries store the amount of incremental electricity produced above the equivalent hourly CCCT output. When the number is negative, then storage from batteries must discharge to fill the gap from the average output from solar to the expected hourly output from the CCCT.

For example, an average December suggests that the solar plant can only produce on average 54 MW per hour for the month. The average output from the CCCT is 240 MW, so the batteries must produce 196 MW-hour on average for each hour of the month. The total energy stored prior to December to meet the month of December deficit is 138,511 MWh.

Each 4-hour battery configuration is capable of storing 4hours X 240 MW (neglecting losses) or 960 MW-hours of energy. Thus to meet the production needs of electricity from battery storage, the number of batteries required equals 144 batteries of 240 MW size, calculated below:

138,511 MW-hours X 1 Battery per 960 MW-hours = 144 Batteries for December

The challenge lies in the fact that battery discharge season begins in October of each year and runs through March. No month during that timeframe is capable of producing electricity from solar to meet the hourly average equivalent of a CCCT. On average, the storage required from batteries to meet the needs across the season would be the sum of the MW-hour deficits in Oct-Mar of each winter. That number is 571,224 MW-hours. The number of batteries required to meet that energy need is 595.

Calculation below:

571,224 MW-hours X 1 Battery per 960 MW-hours = 595 Batteries for winter

Batteries needed for solar based upon the lowest monthly capacity factor?

December is the month with the least amount of solar radiation. The sun is available on average around 8 hours per day in December. To simplify matters, assume that every day in December is average. Thus, 16 hours of storage will meet the requirements. This equates to four batteries.

Batteries needed for wind?

Per the capacity factor calculation, 490 MW of wind machine capability will produce an annual amount of electricity equivalent to the CCCT. In short-time frames, electricity production from wind is much more intermittent and unreliable than solar. However, the monthly production across a year is much more evenly distributed, on average.

Looking at historical data from the Columbia Gorge can give a reasonable expectation of the long durations of no wind generation that may come from Montana based wind. Below are some historical timeframes selected from high load months January and December where generation from our wind contract was essentially zero every hour.

Start Date	Start Hour	End Date	End Hour	Duration (Hours)
Jan 15, 2014	3 PM	Jan 29, 2014	12 PM	333
Dec 24, 2015	11 PM	Jan 12, 2016	8 PM	454
Jan 8, 2019	2 AM	Jan 17, 2019	7 PM	234
Dec 4, 2011	12 AM	Dec 20, 2011	9 AM	394
Dec 4, 2017	3 PM	Dec 16, 2017	7 PM	292

From the table, 460 hours of storage would cover the scenario where the longest amount of time elapsed with zero wind generation. That equates to 115 batteries (460/4).

Resulting functionally equivalent combinations to mimic a CCCT similar to RRGP.

Capital Costs

Capital costs to create a functionally equivalent CCCT are very wide and obviously very dependent upon the assumptions made. However, functionally replacing a base load CCCT from a capital cost perspective requires spending at least 20 times the capital cost of a brand new CCCT.

	Capital Costs for Functionally Equivalent Resources								
Plant Configuration	MW Plant Generation Capability (MW)	Generation Capital Cost ($Million/MW)	Plant Generation Cost ($ Million)	# Batteries	Battery Size (MW)	Battery Capital Cost ($Million/MW)	Battery Life Adjustment Factor	Total Battery Capital Cost ($ Million)	Total Capital Costs ($Million)
Combined Cycle Combustion Turbine	240	1.150	$276	0					**$276**
Solar Plant based upon Annual Capacity Factor - All Winter Storage	692	1.350	$934	595	240	1.400	1.5	$299,880	**$300,814**
Solar Plant based upon December Monthly Capacity Factor	3000	1.350	$4,050	4	240	1.400	1.5	2016	**$6,066**
Wind Plant based upon Annual Capacity Factor - 400 hours of battery	494	1.450	$716	100	240	1.400	1.5	$50,400	**$51,116**

Fixed Annual and Variable Costs

As with capital costs, fixed annual costs and variable costs to create a functionally equivalent CCCT also vary widely.

Plant Configuration	MW Plant Generation Capability (MW)	Generation Annual Fixed Costs per MW ($/MW)	Generation Annual Fixed Costs ($Million)	Generation Variable Cost $/MWh	# Batteries	Battery Size (MW)	Battery Annual Fixed Cost per MW ($/MW)	Battery Annual Fixed Cost ($/Million)	Total Annual Costs ($Million)
Combined Cycle Combustion Turbine	240	10,000	$2.4	$3.0	0			$0.0	**$8.31**
Solar Plant based upon Annual Capacity Factor - All Winter Storage	692	14,550	$10.1	$0.0	595	240	30,000	$4,284	**$4,294.1**
Solar Plant based upon December Monthly Capacity Factor	3000	14,550	$43.7	$0.0	4	240	30,000	$28.8	**$72.5**
Wind Plant based upon Annual Capacity Factor - 400 hours of battery	494	30,000	$14.8	$0.0	100	240	30,000	$720	**$734.8**

Fuel Costs

Wind and Solar have no fuel costs. Natural gas costs can vary widely year to year and decades to decades.

Year One Results – Apples to Apples

Shown below is an apples-to-apples comparison of year 1 costs for all resulting project combinations on a dollar per kilowatt-hour basis at varying fuel price levels. This table takes into account all capital, annual, variable, and fuel costs. Keep in mind the current retail rate for CPU is $0.0816 per kilowatt-hour.

	Year One Cost based upon natural gas price delivered to RRGP ($/KWh)								
Gas Price ($/MMBtu)	$ 2.00	$ 3.00	$ 4.00	$ 5.00	$ 6.00	$ 7.00	$ 8.00	$ 9.00	$ 10.00
Combined Cycle Combustion Turbine	$0.02425	$0.03025	$0.03625	$0.04225	$0.04825	$0.05425	$0.06025	$0.06625	$0.07225
Solar Plant based upon Annual Capacity Factor - All Winter Storage	$10.93	$10.93	$10.93	$10.93	$10.93	$10.93	$10.93	$10.93	$10.93
Solar Plant based upon December Monthly Capacity Factor	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21
Wind Plant based upon Annual Capacity Factor - 400 hours of battery	$1.86	$1.86	$1.86	$1.86	$1.86	$1.86	$1.86	$1.86	$1.86

Caveats and Cautions

This analysis, regardless of its length, is a very simple approach to at least giving an "indicative answer" to the original question of "how much would it cost to replace CPU's River Road Generating plant with a combination of renewable energy and batteries to make the two functionally equivalent"?

With many broad assumptions, most meant to give renewables and batteries the benefit of the doubt, the results can only be interpreted as an order of magnitude close to the actual result at best.

In no way, shape, or form do these results mean the proposed alternative to a CCCT is even possible. Nor, does it indicate that CPU is adverse to actions related to renewables, batteries, or CCCTs.

The analysis is meant simply to shine light on the simple question that as the analysis shows is much harder to answer than it is to ask.

Many studies on broad regional portfolios point to the same answer. It is very expensive to replace reliable dependable and dispatchable power supply with GHG-Free only resources.[7]

[7] http://www.publicgeneratingpool.com/e3-carbon-study/