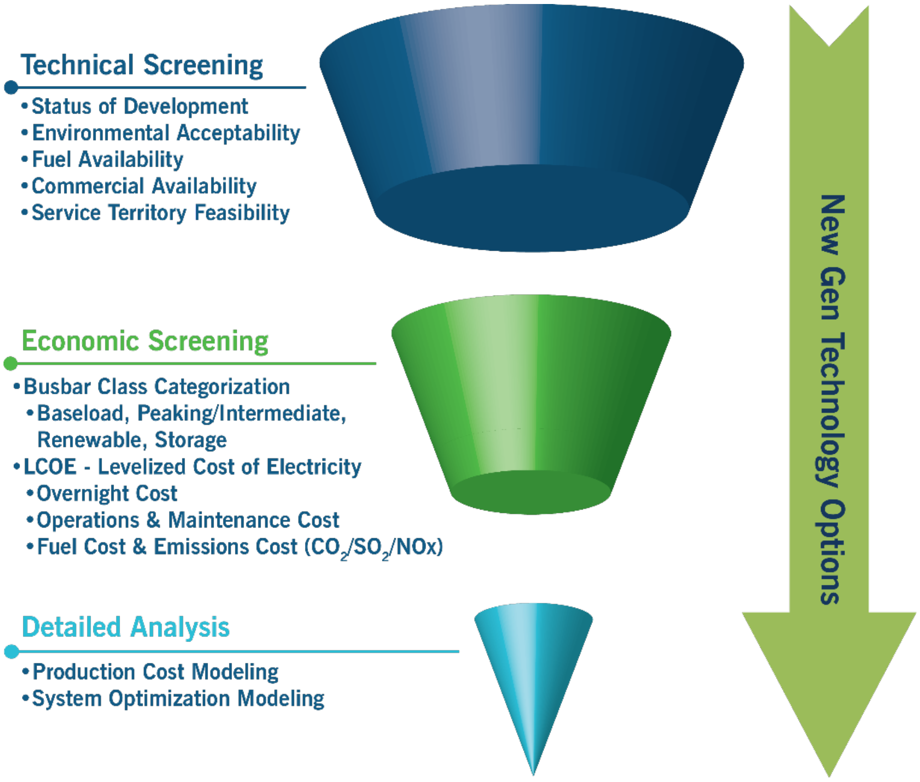
H

Screening of Generation Alternatives

Identifying the set of generation technologies that can serve the future electric load is one of the most critical decisions in the development of the Carolinas Carbon Plan (the "Plan or "Carbon Plan"). To develop a manageable set of generation alternatives for consideration, the Duke Energy Carolinas, LLC ("DEC") and Duke Energy Progress, LLC ("DEP" and, together with DEC, "Duke Energy" or the "Companies") screen generation technologies prior to performing detailed analysis. Generating technologies are screened from both a technical and economic perspective, as illustrated in Figure H-1 below.

Figure H-1: New Generation Technologies Screening Process



In the development of the Carbon Plan, the Companies considered a diverse range of technologies in the categories of baseload, peaking/intermediate, intermittent and storage. In the technical screening process, the technology options are reviewed to determine technical limitations, commercial availability, and feasibility in the Companies' service territories. The economic screening utilizes relative dollar per kilowatt-year ("$/kW-year") versus capacity factor screening curves. The technologies must be technically and economically viable to make it to the detailed analysis phase of the Carbon Plan process. Table H-1 below details the technologies that were evaluated in the screening process for the Carbon Plan. More detail on the technical and economic screening processes is discussed through the remainder of this Appendix and additional detail on the technologies that make it through the technical and economic screening process is included in Appendices I, J, K, L and M.

Table H-1: Technologies Considered in the Carbon Plan Screening Process

Technology	Passed Technical Screening	Passed Economic Screening
Baseload Technologies		
Advanced Reactors	Y	Y
Bio-Energy	N	-
Coal	Y	N
Coal with CCS	Y	N
Combined Cycle F-Class	Y	Y
Combined Cycle J/HA-Class	Y	Y
Combined Cycle with CCS	Y	N
Combined Heat and Power	Y	Y
Conventional Nuclear	Y	N
Fuel Cells	N	-
Fusion Nuclear Reactors	N	-
Geothermal	N	-
Small Modular Reactors	Y	Y
Supercritical CO_2 Brayton Cycle	N	-
Wood Bubbling Fluidized Bed	Y	N
Peaking/Intermediate Technologies		
Aeroderivative Combustion Turbine	Y	Y
F-Frame Combustion Turbine	Y	Y
J/HA-Frame Combustion Turbine	Y	Y
Reciprocating Engine	Y	Y
Intermittent Technologies		
Hydroelectric	N	-
Landfill Gas	Y	N
Offshore Wind	Y	Y

Technology	Passed Technical Screening	Passed Economic Screening
Intermittent Technologies		
Onshore Wind	Y	Y
Solar PV	Y	Y
Solar Steam Augmentation/ Concentrated Solar Power	N	-
Wave and Tidal	N	-
Storage Technologies		
Advanced Compressed Air	Y	Y
Chemical	N	-
Conventional Compressed Air	N	-
Flow Battery	Y	Y
Gravity	N	-
Lead Acid Battery	N	-
Lithium-ion Battery	Y	Y
Liquid Air	N	-
Liquid Metal	N	-
Metal Aqueous/Oxide Battery	N	-
Metal Alloy Battery	N	-
Nickel Hydrogen Battery	N	-
Organic Rankine Cycle	N	-
Phase Change	N	-
Pumped Storage Hydro	Y	Y
Solid State Li-ion	N	-
Sub-Terranean Pumped Storage	N	-
Thermal Pumped Heat	N	-
Thermal Heat	N	-

Several gas-fueled generation technologies are included in the baseload and peaking categories. For the economic analysis, all gas-fueled technologies are assumed to utilize natural gas. However, the utility industry is evaluating alternative fuels for gas technologies including hydrogen and various forms of biofuels. Although near-term deployment of hydrogen and biofuels may be limited, the industry is working on producing low CO_2 intensity fuels that the Companies believe will be available beginning in the 2030s. Additional information on the potential for low-carbon fuels can be found in Appendix O (Low-Carbon Fuels and Hydrogen).

Technical Screening and Summary of Technologies Screened Out

The first step in the Companies' process of screening generation alternatives is the technical screening of the technologies to eliminate those with technical limitations, commercial availability issues, or that are not feasible in the Companies' Carolinas service territories. In previous Integrated Resource Plan ("IRP") submittals, the Companies have only included technologies that were available within the 15-year planning period, but due to the extended planning time horizon of the Carbon Plan (through 2050), additional technologies are considered in this Plan. Appendices J, K, L and O are included to provide additional detail on technologies that are included in the screening process that do not have previous operating experience in the Carolinas. The full set of technologies that have been screened in during the technical review are illustrated in Table H-1 above.

In this section, the Companies provide a brief explanation of the technologies excluded in the technical screening process and the basis for their exclusion.

Baseload Technologies

Bioenergy: Economics and limited supply both challenge large-scale bioenergy development. Existing biofuels, such as biodiesel and ethanol, are more expensive than their hydrocarbon equivalents and have minimal carbon reduction benefits. Additionally, biodiesel and ethanol have difficulties related to replenishment and operation. Biofuels could be an alternative fuel source in the future if price and CO_2 intensity can be reduced. The Companies will continue to reevaluate bioenergy in future Carbon Plan updates.

Fuel Cells: Although originally envisioned as a competitor to combustion turbines and central power plants, fuel cells are now mostly targeted to distributed power generation systems. The size of the distributed generation applications ranges from a few kilowatts ("kW") to potentially tens of megawatts ("MW"). Cost and performance issues have generally limited the application of fuel cells to niche markets and/or subsidized installations. While some research and development continues, this technology is not commercially viable/available for utility-scale application but will be reviewed in future Carbon Plan updates.

Fusion Nuclear Reactors: Nuclear fusion energy has been researched for many decades, as the technology holds significant promise for energy production, specifically in a low-carbon world. There have been significant advancements in fusion over the last several years, including the scientific community approaching net-energy gain from a fusion reaction. However, commercial deployment of fusion energy is expected to be outside of the planning range for the Carbon Plan due to the long timeframe for deployment, which will require net-energy gain from fusion reaction, sustained net-energy gain from fusion reaction, development of a commercial fusion energy product and demonstration of the commercial product. The Companies will continue to monitor the technology as a potential future carbon-neutral energy source.

Geothermal: There are no suitable geothermal resources in the Carolinas to develop a power generation project, as illustrated in Figure H-2 below. Advanced geothermal is under development and demonstration projects are being evaluated across the western U.S. Recent developments in deep direct-use geothermal may expand the applicability of geothermal into some of the less favorable geological formations identified in Figure H-2. These direct-use geothermal technologies have not yet reached commercial status, so the technology is considered outside the planning horizon for the

Carbon Plan. The Companies will continue to monitor advancements of this technology as it may present geothermal energy capability within the Carolinas in the future.

Figure H-2: Location of Identified Hydrothermal Sites and Favorability of Deep Enhanced Geothermal Systems ("EGS")

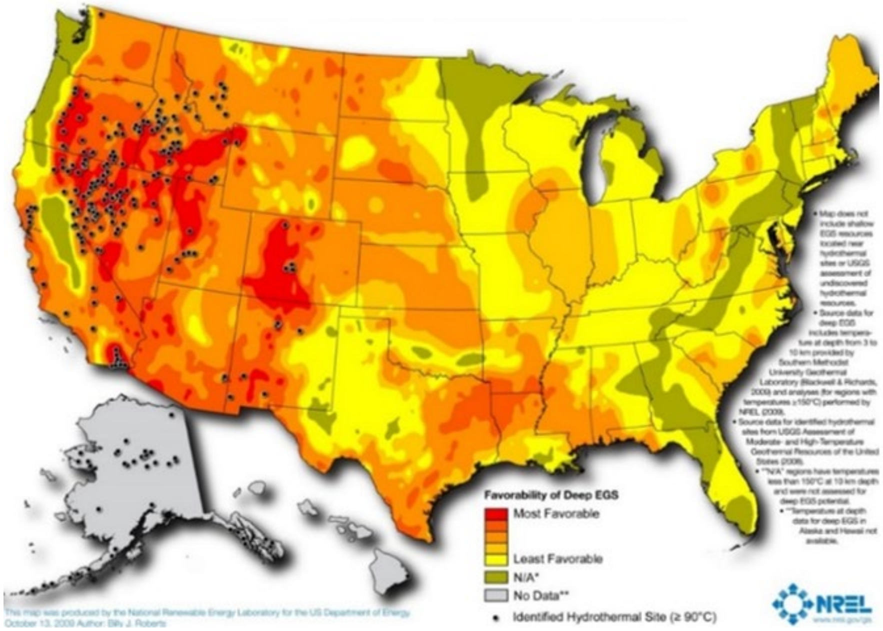


Figure source: NREL

Supercritical CO_2 ("sCO_2") Power Cycle: This technology remains in the demonstration stage; early pilot issues have kept the technology from reaching commercial status. Duke Energy will continue to monitor pilot and early commercial sCO_2 Power Cycle projects to determine if the technology passes the technical screening in future years. A low-CO_2-emitting sCO_2 Power Cycle facility would likely require carbon capture, utilization and storage ("CCUS"), which also poses some commercialization concerns. The additional details on sCO_2 and CCUS that are highlighted below are directly in response to the Commission's request for such information as outlined in the November 19, 2021 *Order Accepting Integrated Resource Plans, REPS and CPRE Program Plans with Conditions and Providing Further Direction for Future Planning*, Docket No. E-100, Sub 165.

In sCO_2 power systems, CO_2 is utilized as the working fluid, replacing the air, water or steam used in traditional power generation systems. At just above its critical temperature and pressure, CO_2 is liquid-like, requiring dramatically less pumping power compared to air and nitrogen, which reduces operating cost. The footprint for a 300 MW sCO_2 turbine is approximately one tenth of the size of a traditional 300 MW steam turbine due to the high energy density of the sCO_2.

There are two configurations of sCO_2 systems: indirect heating and direct-fired cycles. Indirect cycles can be heated with any external source, such as natural gas, nuclear, solar thermal or geothermal, and are similar to a traditional steam boiler. The CO_2 flows in a closed loop where it is compressed, heated, and expanded to produce power generation without any condensing within the cycle. In a direct-fired cycle, combustion of a fuel occurs within the sCO_2 system. A compressed stream of CO_2 proportional to the amount of fuel combusted is produced and extracted. Compared to a traditional carbon capture system where compression must take place prior to introduction into a pipeline, this stream is at pressure due to the nature of the sCO_2 system.

Carbon Capture, Utilization and Storage ("CCUS") Technologies: CCUS technologies involve the capture, transport and use of CO_2 from fuel combustion or industrial processes. CO_2 can be transported via ship or pipeline and used as a resource to create valuable products and services or permanently stored underground in geological formations. CCUS technologies provide the foundation for carbon removal when CO_2 is produced from bio-based processes.

Carbon capture tends to fall into three categories: pre-combustion, oxyfuel combustion, and post-combustion capture, all of which the Companies are closely monitoring.

- Pre-combustion capture is the separation of CO_2 in a coal gasification process. CO_2 can also be removed from natural gas for hydrogen production but there are a small number of projects performing this function.

- Oxy-fuel combustion is the combustion of fossil fuels in a nearly pure oxygen atmosphere, offering a purer stream of CO_2. Capital costs, energy consumption, and operational challenges are the primary barriers for these systems.

- Post-combustion capture involves the removal of CO_2 from the flue gas stream of coal and natural gas combined cycle power plants. This technology is the most widely developed and commercially available of the three carbon capture processes.

Once CO_2 is captured, it must then be compressed and transported to a storage location. Addressing the power required for these processes poses a significant challenge. There are two primary options for storing captured CO_2: utilization and geologic sequestration. Utilization recycles CO_2 into another form or industrial use. Geologic sequestration stores CO_2 in porous saline aquifers in the sub-surface of the Earth. Because North Carolina is not an ideal location for geologic storage, any captured CO_2 would need to be transported via pipeline outside the State.

Intermittent Technologies

Hydroelectric Power ("Hydro"): Hydro describes a set of technologies that produce electricity from the movement of water, generally by using a hydraulic turbine. Hydro power is extremely site-specific, requiring a relatively large water source and the ability to manage it through a dam or other structures. The Companies began their operations in the Carolinas as a hydroelectric company. While Hydro plants continue to be part of the generation portfolio in the Carolinas, they make up a small portion of the generation today. In addition to the lack of available new sites for development of hydro in the Carolinas, building new hydro facilities is very costly.

Solar Steam Augmentation/Concentrated Solar Power: These systems utilize solar thermal energy to supplement a Rankine steam cycle, similar to a fossil generating plant. The supplemental steam is integrated into the steam cycle and supports additional MW generation similar in concept to the purpose of duct firing a heat recovery steam generator. Solar steam augmentation/concentrated solar power utilizes mirrors to concentrate solar energy instead of collecting energy through solar panels. This process requires specific weather conditions, mostly hot dry locations, and most current installations are in deserts like the North American Southwest. As these systems utilize mirrors instead of solar panels, the economics tend to favor toward solar steam augmentation when the prices for solar panels are higher. However, as the price of solar panels continues to drop, solar steam augmentation's economics just don't work out as compared to just installing solar panels. However, Duke Energy will continue to monitor developments in solar steam augmentation, if there are changes to the technology in the future that change the assessment.

Wave and Tidal Power: Wave and tidal power systems are developing technologies focused on harnessing energy from the ocean. There are a few wave power systems currently operational today, but the technology is still far from being considered commercially viable and has not been a focus of development for the Companies. Tidal power typically requires large variation in tides, which does not exist within the Carolinas. There are companies pursuing the advancement of these technologies in the U.S., and the Companies will continue to monitor these technologies for potential options in future Carbon Plan updates.

Storage Technologies

Storage technologies continue to be explored by a variety of companies. The range of technologies under development is vast. Although some storage technologies passed the technology screening, the majority are still in a pre-commercial status. The Companies will continue to evaluate the technologies that didn't pass the technical screening phase to be studied as future options for storage, which includes advanced lead acid batteries, liquid metal batteries, sodium batteries, metal air batteries, metal oxide batteries, subterranean pumped storage, gravitational energy, flywheel energy, liquid air energy, chilled water, molten salt, silicon, concrete, sand and phase change storage. Duke Energy will continue to monitor the developments and pilots of the various storage options to determine which designs have reached commercial status.

Economic Screening

Duke Energy screens all technologies using relative dollar per kilowatt-year ("$/kW-year") versus capacity factor screening curves, also referred to as busbar curves. By definition, the busbar curve estimates the revenue requirement (i.e., life cycle cost) of power from a supply option at the "busbar," the point at which electricity leaves the plant (i.e., the high side of the step-up transformer). The screening uses a spreadsheet-based curve model developed by Duke Energy that is considered proprietary, confidential and competitive information. Screening curves were developed for each technology to show the economics with and without carbon costs in the four major categories, baseload, peaking/intermediate, intermittent and storage.

Duke Energy assessed storage technologies independently through an additional set of busbar curves because they are not traditional generating resource options. In addition, the Companies did not associate any charging cost with the storage busbar buildup. This charging cost is excluded because the source used to “charge” the storage resource is dependent upon the next marginal unit in the dispatch stack. For resource options inclusive of, or coupled with, storage, Duke Energy assumed that the storage resource is directly charged by the generating resource (e.g., solar photovoltaic plus battery storage option).

Information Sources

The cost and performance data for each technology assessed in the economic screening is based on research and information from several sources. The primary source of data for supply-side options are a third-party engineering study from Burns & McDonnell and marketing reports from Guidehouse. Duke Energy also assessed a significant amount of data from a variety of its internal departments. In addition, the Companies consulted the following resources to ensure costs and performance data are aligned with industry information: Electric Power Research Institute (“EPRI”) Technical Assessment Guide (“TAG®”), the Energy Information Administration’s (“EIA”) Annual Energy Outlook (“AEO”), National Renewable Energy Laboratory’s (“NREL”) Annual Technology Baseline (“ATB”), and Lazard’s Levelized Cost of Energy (“LCOE”).

Duke Energy prepared fuel and operating cost estimates from both internal development and the sources listed above. Information and estimates from external studies are not site-specific, but generally reflect the costs and operating parameters for installation in the Carolinas. The Companies made every effort to ensure that capital costs, operating and maintenance costs (“O&M”), fuel costs and other parameters are current and include similar scope across the technologies being screened. The supply-side screening analysis uses the same fuel prices for coal and natural gas, and allowance prices for NO_x, SO_2 and CO_2 as those utilized downstream in the detailed analysis.

Capital Cost Forecast

Duke Energy developed a capital cost forecast with support from a third party to project the costs of all resource technologies passing the technical screening phase. The Technology Forecast Factors were sourced from the EIA Annual Energy Outlook 2021, which provides cost projections for various technologies through the planning period as an input to the National Energy Modeling System (“NEMS”) utilized by the EIA for the AEO. This data creates a linkage between the construction cost and commodity price associated with a given technology.

The resulting Forecast Factor Table developed from the EIA technology maturity curves for each corresponding technology screened is depicted in Table H-2 below.

Table H-2: Forecast Factor Table by Technology

Year	Solar PV-Tracking	Solar-PV-Tracking w/storage	Battery Storage	Onshore Wind	Offshore Wind	Small Modular Reactor	Pumped Storage Hydro	Frame CT	2x1 Combined Cycle	2x1 Combined Cycle w/CCS
2022	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2023	0.957	0.944	0.888	1.010	1.001	1.000	0.987	1.000	1.000	1.000
2024	0.920	0.899	0.804	1.010	0.999	1.000	0.973	0.990	1.000	0.990
2025	0.888	0.867	0.775	1.010	0.997	1.000	0.961	0.970	0.990	0.990
2026	0.868	0.849	0.760	1.010	0.984	1.000	0.950	0.960	0.990	0.980
2027	0.851	0.830	0.739	1.000	0.969	0.980	0.940	0.950	0.970	0.960
2028	0.829	0.806	0.705	0.990	0.954	0.970	0.932	0.930	0.960	0.950
2029	0.808	0.785	0.684	0.970	0.937	0.950	0.922	0.910	0.940	0.930
2030	0.788	0.765	0.662	0.960	0.919	0.940	0.912	0.890	0.930	0.910
2031	0.770	0.746	0.640	0.950	0.788	0.920	0.900	0.880	0.910	0.890
2032	0.750	0.727	0.620	0.930	0.773	0.900	0.888	0.870	0.900	0.880
2033	0.740	0.711	0.600	0.920	0.660	0.890	0.876	0.850	0.890	0.860
2034	0.720	0.695	0.580	0.910	0.647	0.870	0.863	0.840	0.870	0.840
2035	0.710	0.681	0.560	0.890	0.634	0.860	0.851	0.820	0.860	0.830
2036	0.690	0.669	0.550	0.880	0.622	0.840	0.840	0.810	0.850	0.810
2037	0.680	0.657	0.550	0.870	0.607	0.830	0.827	0.800	0.830	0.800
2038	0.670	0.646	0.540	0.860	0.576	0.810	0.814	0.790	0.820	0.780
2039	0.660	0.636	0.540	0.850	0.565	0.800	0.802	0.780	0.810	0.770
2040	0.650	0.625	0.530	0.840	0.555	0.790	0.790	0.760	0.800	0.760
2041	0.630	0.614	0.530	0.830	0.544	0.780	0.777	0.750	0.790	0.740
2042	0.620	0.604	0.520	0.820	0.533	0.760	0.765	0.740	0.780	0.730
2043	0.610	0.594	0.520	0.810	0.523	0.750	0.754	0.730	0.770	0.720
2044	0.600	0.584	0.510	0.800	0.513	0.740	0.743	0.720	0.760	0.700
2045	0.590	0.574	0.510	0.790	0.503	0.730	0.731	0.710	0.750	0.690
2046	0.580	0.563	0.500	0.780	0.493	0.710	0.720	0.700	0.740	0.680
2047	0.560	0.553	0.500	0.770	0.482	0.700	0.708	0.690	0.730	0.660
2048	0.550	0.542	0.490	0.760	0.471	0.690	0.695	0.680	0.720	0.650
2049	0.540	0.532	0.490	0.740	0.463	0.680	0.684	0.660	0.700	0.640
2050	0.530	0.522	0.480	0.730	0.457	0.660	0.672	0.650	0.690	0.620

Note: Data source EIA – Annual Energy Outlook 2021

Benefits and Challenges of Levelized Cost of Electricity ("LCOE")

LCOE is a metric that can be used to compare generation resources to determine the lowest cost over a set period with a specific set of assumptions. The LCOE considers the full cost of the asset including capital and operating and maintenance ("O&M") expenses, and it also considers the expected capacity factor and operating life of the asset. However, LCOE has limitations when comparing technologies, which can create uneven results when considering different use cases (e.g., baseload vs. peaking), capacity values (e.g., Effective Load Carrying Capability "ELCC"), and/or operating life (e.g., 15 vs. 35 years). Additional information on the limits of LCOE from the EIA's analysis can be found below.

> As often noted by the EIA, the direct comparison of LCOE across technologies to determine the economic competitiveness of various generation alternatives is

> problematic and potentially misleading. Actual plant investment decisions are affected by the specific technological and regional characteristics of a project, which involve numerous other considerations. The projected utilization rate, which depends on the load shape and the existing resource mix in an area where additional capacity may be needed, is one such factor. The existing resource mix in a region can directly affect the economic viability of a new investment through its effect on the economics surrounding the displacement of existing resources. For example, a wind resource that would primarily displace existing natural gas generation will usually have a different value than one that would displace existing coal generation. A related factor is the capacity value, which depends on both the existing capacity mix and load characteristics in a region. Since load must be balanced on a continuous basis, dispatchable technologies generally have more value to a system than non-dispatchable ones, including those whose operation is tied to the availability of an intermittent resource.[1]

Screening Results

The busbar models include the total costs associated with owning and maintaining a technology type over its lifetime and computes a levelized $/kW-year value over a range of capacity factors. All information is based on the current technology capital costs and does not consider capital cost reductions for each technology in the future. The Companies repeat this process for each supply technology to be screened resulting in a family of curves. The lower envelope along the curves represents the least costly supply options for various capacity factors or unit utilizations. Some technologies have screening curves limited to their expected operating range on the individual graphs. Lines that never become part of the lower envelope, or those that become part of the lower envelope only at capacity factors outside of their relevant operating ranges, have a very low probability of being part of the least cost solution, and generally can be eliminated from further analysis.

Results of the baseload screening show that natural gas combined cycle generation continues to be the least-cost baseload resource. With lower gas prices, larger capacities and increased efficiency, natural gas combined cycle ("CC") units have become more cost-effective at higher capacity factors in all screening cases. Although combined heat and power ("CHP") can be competitive with CCs, it is site-specific and requires a local steam user and electrical load. Advanced nuclear costs approach cost parity with CCs at high-capacity factors in a scenario with a carbon price included. There is a clear gap between combined cycle and advanced nuclear and all remaining baseload technologies in a carbon scenario, which includes conventional nuclear, coal, coal with carbon capture sequestration ("CCS"), combined cycle with CCS, landfill gas, and wood bubbling fluidized bed. To reduce the total number of options considered for capacity expansion, the Companies economically screened out coal, coal with CCS, combined cycle with CCS, landfill gas, and wood bubbling fluidized bed.

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[1] U.S. Energy Information Administration, Assessing the Economic Value of New Utility-Scale Electricity Generation Projects, at 1 (Jul. 2013), *available at* https://www.eia.gove/renewable/workshop/gencots/pdf/lace-lcoe_070213.pdf.

The peaking technology screening included F-Frame and J/HA-Frame combustion turbines (“CT”), fast start aero-derivative combustion turbines, and fast start reciprocating engines. The screening curves show the frame combustion turbines to be the most economic peaking resource at lower capacity factors unless there is a special application that requires the fast start capability of the aero-derivative CTs or reciprocating engines. Reciprocating engine plants offer the lowest heat rates and fastest start times among simple-cycle options. Aeroderivative gas turbines remain in close contention with reciprocating engines. Should the Companies identify a need for one of these two types of resources, they will perform a more in-depth analysis. The smaller reciprocating engines show a significantly higher cost than the other peaking options and would not be considered for capacity expansion.

The intermittent screening curves show that solar continues to be a more economical alternative than other intermittent resource options. Solar and wind projects are technically constrained from achieving high-capacity factors making them unsuitable for intermediate or baseload duty cycles. Although fixed-tilt solar has the lowest $/kW-year cost, the bifacial single-axis tracking solar has the highest capacity factor. All intermittent technologies are considered for capacity expansion planning due to their varying attributes and the need for increased renewables with potential capacity limits. Additionally, the varying capacity factors and profiles of each renewable resource considered provide complementary benefits to the system.

Energy storage has become an increasingly important asset as companies add more intermittent resources to their portfolios. Energy storage can provide a variety of benefits to the grid and overall resource portfolio. Additional information on energy storage can be found in Appendix K (Energy Storage). For the screening results, the lowest $/kW-year option for energy storage was 4-hour duration lithium-ion storage, as expected. However, batteries have a variety of use cases, and longer duration storage can be more useful than shorter duration storage in certain cases. Additionally, the $/kWh decreases as the duration of the storage increases. So, although the 4-hour duration lithium-ion battery storage asset had the lowest screening cost, the specific application of the storage option will determine which storage option is the best fit for its use case. Additionally, as increasing capacity of renewables is added to the system, longer duration storage will be required. To reduce the total number of storage options included in capacity expansion planning, only one of the 4-, 6-, and 8-hour lithium-ion options was modeled.

The screening curves are useful for comparing costs of resource types at various capacity factors but cannot be solely utilized for determining a long-term resource plan because future units must be optimized with an existing system containing various resource types. Results from the screening curve analysis provide guidance for the technologies to be further considered in the more detailed quantitative analysis phase of the planning process.

Conclusion

After evaluating all technologies for both technical and economic screening, a subset of the initial technology list remains for capacity expansion planning. The full list of technologies that passed the economic screening can be seen in Table H-1 of this Appendix. Several technologies from each baseload, peaking/intermediate, intermittent, and storage are included in the expansion planning analysis to allow the model to economically select the most viable portfolio to meet future carbon planning targets.

Duke Energy will perform technical and economic screening of available technologies with each update to the Carbon Plan, observing changing costs as available technologies continue to mature. Likewise, Duke Energy will continue to monitor the technologies that were screened out technically in this initial filing for commercial readiness and usefulness to a future update of the Plan.