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Moving Towards Clean Power in Georgia

A New View of Georgia's Electric Grid

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Overview

We have analyzed the potential for decarbonizing the electric grid in the State of Georgia, using a new modeling tool that allows an hour-by-hour analysis of grid behavior. This model reveals important features of the grid not disclosed by existing models. Using data from the Georgia Power Company, including its current Capacity Expansion Plan, we have identified alternative plans that could reduce or eliminate greenhouse gas emissions and prepare the state for further decarbonization of its economy. The new model provides extensive quantitative information on source capacity requirements and costs, as well as details of the operation of each energy source.

Our findings emphasize the need for large firm dispatchable emission-free resources – energy sources that are always available and able to support whatever additional electric load is present on the grid. Due to the expected electrification of transportation and the heating of buildings, such a reliable, dispatchable resource must operate not just as occasional backup, but as the backbone of the system for most of the year. Without such a resource, the state will have a grid that is unreliable and subject to repeated rolling blackouts, or that continues to emit large quantities of greenhouse gases. Among existing technologies, only nuclear power will be able to meet this need at the scale required. The alternate plans we present will meet the need for reliable and affordable emission-free power while avoiding a vast expensive, environmentally destructive expansion of solar, wind, and battery storage.

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This report is available at https://bit.ly/41RxEys.

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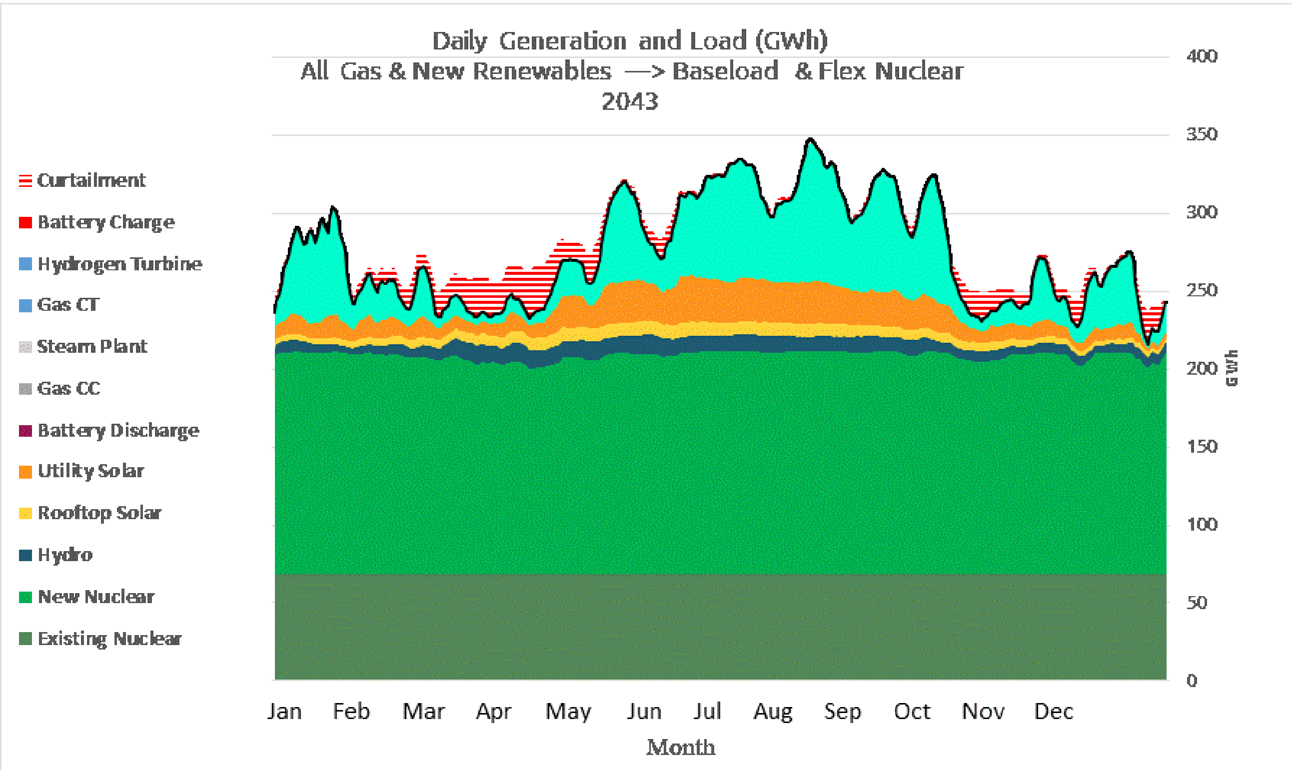


Energy Source	Capacity (MW)	Output (GWh/yr)	Capacity Factor (%)	% Load
Existing Nuclear	2,978	25,061	96.1%	24.9%
New Nuclear	6,430	51,097	90.7%	50.8%
Hydro	1,985	3,181	18.3%	3.2%
Rooftop Solar	1,500	2,288	17.4%	2.3%
Utility Solar	3,631	5,820	18.3%	5.8%
Flex Nuclear	9,000	13,102	16.6%	13.0%
Load		100,549		100.0%

* Battery charging included in solar and wind generation.

Curtailment	2,851	2.8%

Total Generation Cost ($/MWh) $ 92.87

Introduction: The challenge of electrification

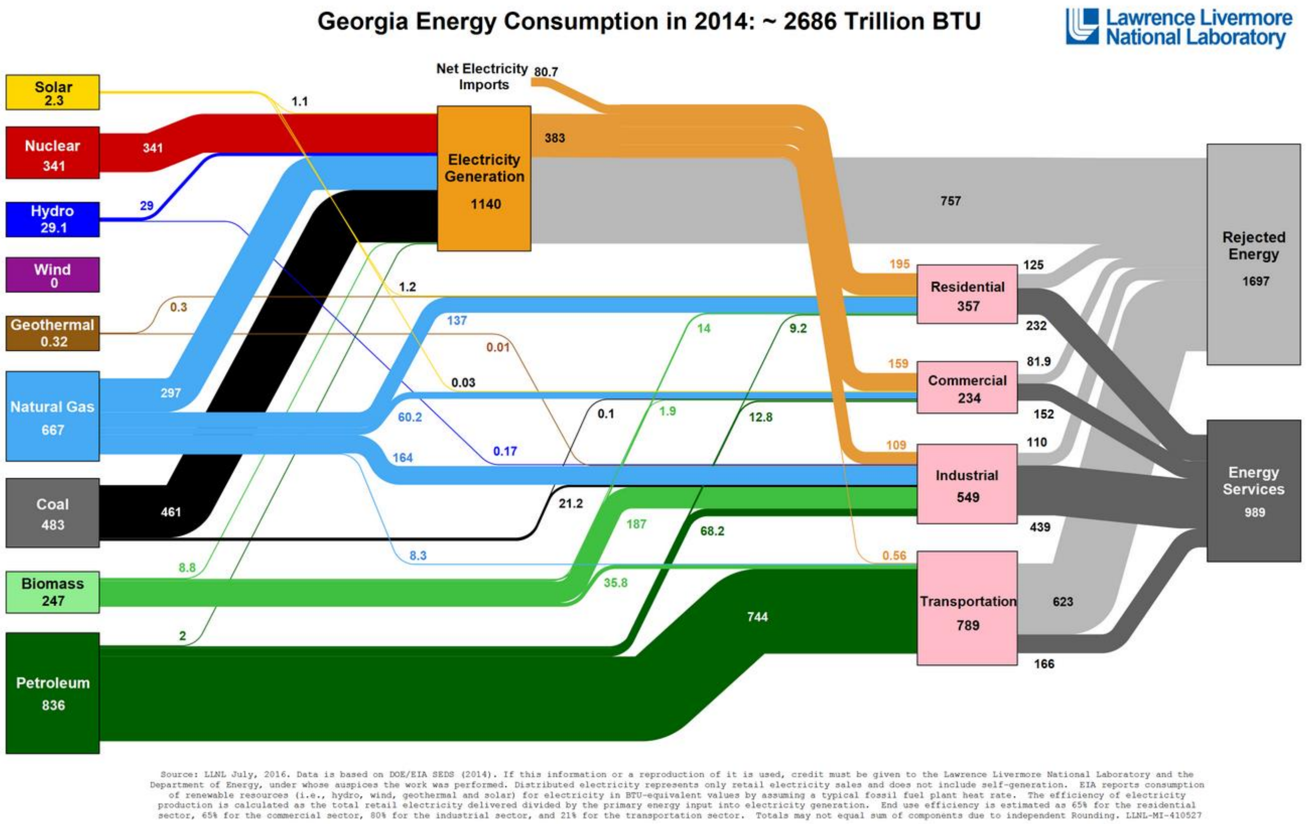
Electricity accounts for 24.3% of Georgia's consumption of energy, but that share is growing. In 2022, 60% of that electricity was generated by the burning of fossil fuels. In the coming years, this will change as Georgia, along with the rest of the nation and the world, gradually shifts to energy sources that don't emit greenhouse gases, especially carbon dioxide and methane. Already, the Georgia Power company has started up Units 3 and 4 at the Vogtle Plant, nuclear-powered generators each capable of generating 9% of the state's electric power. This report suggests that there should be more to come in future years.

To address the issue of climate change, the burning of fossil fuels has to be curbed and eventually eliminated, not only in generating electricity but in transportation and the heating of homes and factories. We know how to generate "clean", that is, emission-free electricity using solar, wind, and nuclear power. It is generally agreed, then, that we should move toward electrifying everything with electric vehicles, electric heat pumps, etc. First, though, we have to move toward emission-free electricity. This report focuses on that starting point, the electric grid, while recognizing that it is not the only, not even the largest, use of fossil fuels in our modern society.

In this report we will utilize data from the Georgia Power Company, which provides 65% of the state's electric power and 80% of its grid-based power[1] The following Sankey energy flow diagram, Figure 1 (the newest available), shows overall energy use in Georgia in 2014. Electricity has continued to be a major consumer of fossil fuels, but other sectors pose major challenges as well, and these will have to be faced if we are to curb the emission of greenhouse gases and contain climate change.

[1] According to the EIA, total electric production in Georgia in 2022 was 129 TWh. Of this, 105 TWh was produced by electric utilities, of which 84 TWh was produced by Georgia Power. Another 23 TWh was produced by independent power producers (IPP).

Figure 1



As this figure shows, coal has been a major source of power in Georgia. Its use continues today, but it is declining and will be eliminated, in accordance with Georgia Power's plans, within the next ten years. However, natural gas (methane, a fossil fuel) continues to be a major component of the state's electric generating system, and Georgia Power plans to add to it in the coming years as the electric load increases. In this report, we examine alternatives to this continuance of the burning of fossil fuels.

Georgia Power's plan for its future electric grid

The State of Georgia has no plan, at present, for fully decarbonizing either its electric grid or, beyond that, the state's overall energy use. However, the Georgia Power Company (GPC) does plan to reduce its carbon footprint over the coming decades. (It does not have a plan to achieve a zero-emission grid, though its parent company, the Southern Company, [does](#).)

Georgia Power's plans are laid out in their 2022 and 2023 Update Integrated Resource Plans. These IRPs provide their projections of electrical demand through 2043 and their planned additions to generation capacity to meet this demand. We focus on Georgia Power's base case, which they refer to as a "moderate gas, zero-dollar carbon" (MG0) scenario. Additional gas-powered plants as well as solar facilities are described, along with a small addition of nuclear facilities. Overall, they project 22% growth in demand by 2043. They plan on this being met by a 44% increase in generating capacity, including a 46% increase in fossil fuel capacity.

We use in this report the planning information which Georgia Power has released to the public. Much detail is treated as proprietary and is redacted in the publicly available documents. Further, Georgia Power has not provided to the public the underlying modeling that would explain their plans for capacity growth or enable the examination of potential alternatives. We fill this critical information gap by applying a new computer model to analyze the implications of this plan for the future of Georgia's electric grid.

An hour-by-hour simulation of Georgia's future electric grid

We have used a model that performs an hour-by-hour analysis of projected electric demand to show how the sources assumed in Georgia Power's scenario will behave, hour by hour, when serving the demand they project. Electric demand in 2043 is drawn from Georgia Power's projections. These incorporate Georgia Power's estimates of added demand from electric vehicles and the electrification of buildings. We do not attempt to model unspecified import and export of energy in the Georgia Power grid.

The shape of hourly demand over the year is based on Georgia Power's records for 2019, prior to the disruptions caused by the Covid pandemic. While the installed capacities of in-state generation sources are taken from Georgia Power's planned

Our grid simulator is an adaptation of the model retirements and expansions, their energy production and resulting capacity factors are dynamically calculated by our simulator. We assume nuclear power plant licenses are extended beyond their current expiration dates into the 2040s, and existing or planned power purchase agreements are extended.

To account for the weather's influence, the hourly solar and wind output is computed using hourly solar and wind data for 2022 from the National Solar Radiation Database of the National Renewable Energy Laboratory.

The model we use was developed for New England by Reiner Kuhr and Ahmad Nofal, experienced energy engineers and leaders of the Center for Academic Collaboration Initiatives (CACI).[2] The CACI approach uses spreadsheet software to calculate, for each hour of the year, how the available energy sources, including battery storage and any dispatchable resources, will be used to meet the projected electric load. [3] The batteries are assumed to be charged by the solar and wind facilities, since those are emission-free sources whose use for this purpose does not add any cost to the system. (By contract, of course, if the gas-fired or nuclear-powered generators were used to charge the batteries, they would add cost as well as emissions if gas were used.) When the non-dispatchable sources – hydro[4], baseload (always-on) nuclear, solar, and wind – are able to meet the load, any excess power is used to charge the batteries. If they are unable to meet the demand, batteries are called upon to fill the gap.

The model calls upon a dispatchable resource — either gas or nuclear, whichever is available — to meet the remaining load. (Appendix A explains the working of the CACI model in more detail.) In our modeling, to quantify the characteristics of a dispatchable emission-free resource — frequently referred to as a DEFR — we use the parameters of

[2] https://www.dropbox.com/scl/fi/2qf8z46u511jfx81vyvx9/Technical-Economic-Limits-for-Renewable-Power-Integration-in-New-England-Full-Report.pdf?rlkey=dzkcvvehuritk12tg6mzbbizw&st=l6ls99ed&dl=0

[3] A dispatchable resource is one that is always available and can supply whatever additional electric output is needed at any point in time. Gas turbines, as well as battery and thermal storage can be used in a dispatchable mode.

[4] Though hydro is used today to respond to some of the variation in system demand, for simplicity in using this model, it is treated as a non-dispatchable fixed resource in our work here.

the Natrium, a small modular nuclear reactor (SMR) currently being developed by TerraPower and GE-Hitachi. The Natrium design integrates a 345 MW fast neutron reactor coupled to molten salt thermal storage capable of yielding an output of 500 MW for up to five-and-a-half hours.[5] The DEFR is treated as entirely dispatchable from 0 up to 500 MW. We adjust the size of the dispatchable source so that the overall system meets the load for every hour of the year without having any unmet load.[6]

The base year 2022

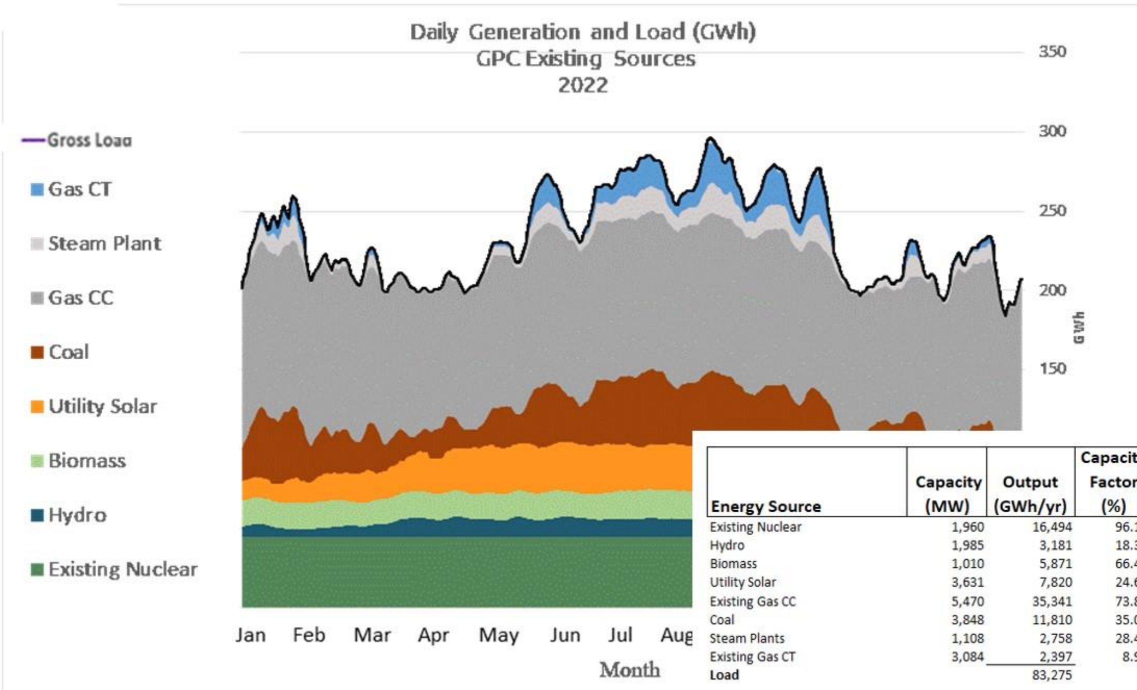
Our base year providing solar, wind, and load patterns is 2022, the most recent year for which full system data is available. Figure 2 shows the results of our analysis for every day of 2022. It displays the contribution of each energy source in meeting the electric load from January 1 to December 31, 2022.

Table B-Base in Appendix B gives detailed quantitative results for 2022. In Figure 2 we can see the existing nuclear facilities and baseload hydro, the existing solar facilities, the burning of coal, and finally, gas-burning plants meeting the rest of the varying load. Already, coal is much reduced from its role in 2014, gas has become the dominant source of power, and solar is beginning to play a significant part in meeting Georgia's electric needs.

[5] https://natriumpower.com/reactor-technology

[6] For an overview of the dispatchability of nuclear plants, see https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BA0F5C88B-0000-C521-AAAD-996DCC98AF0F%7D

Figure 2



Energy Source	Capacity (MW)	Output (GWh/yr)	Capacity Factor (%)	% Load
Existing Nuclear	1,960	16,494	96.1%	19.8%
Hydro	1,985	3,181	18.3%	3.8%
Biomass	1,010	5,871	66.4%	7.1%
Utility Solar	3,631	7,820	24.6%	9.4%
Existing Gas CC	5,470	35,341	73.8%	42.4%
Coal	3,848	11,810	35.0%	14.2%
Steam Plants	1,108	2,758	28.4%	3.3%
Existing Gas CT	3,084	2,397	8.9%	2.9%
Load		83,275		100.0%

Note 1: Steam plant – Gas-or oil-fired boilers & steam turbines
Gas CT –gas-fired combustion turbines
Gas CC = gas-fired combined cycle plants
Biomass = Burning of wood and municipal waste
Note 2: All annual graphs are subject to 7-day smoothing to improve their readability.

Georgia Power's Capacity Expansion Plan

In its 2023 Update to the IRP, Georgia Power has put forth a Capacity Expansion Plan for the next two decades, preparing for what it expects to be major growth in demand over that period. Their plan is shown visually in Figure 3. Coal will be phased out while solar, wind, batteries, and gas will each grow substantially.

Figure 3

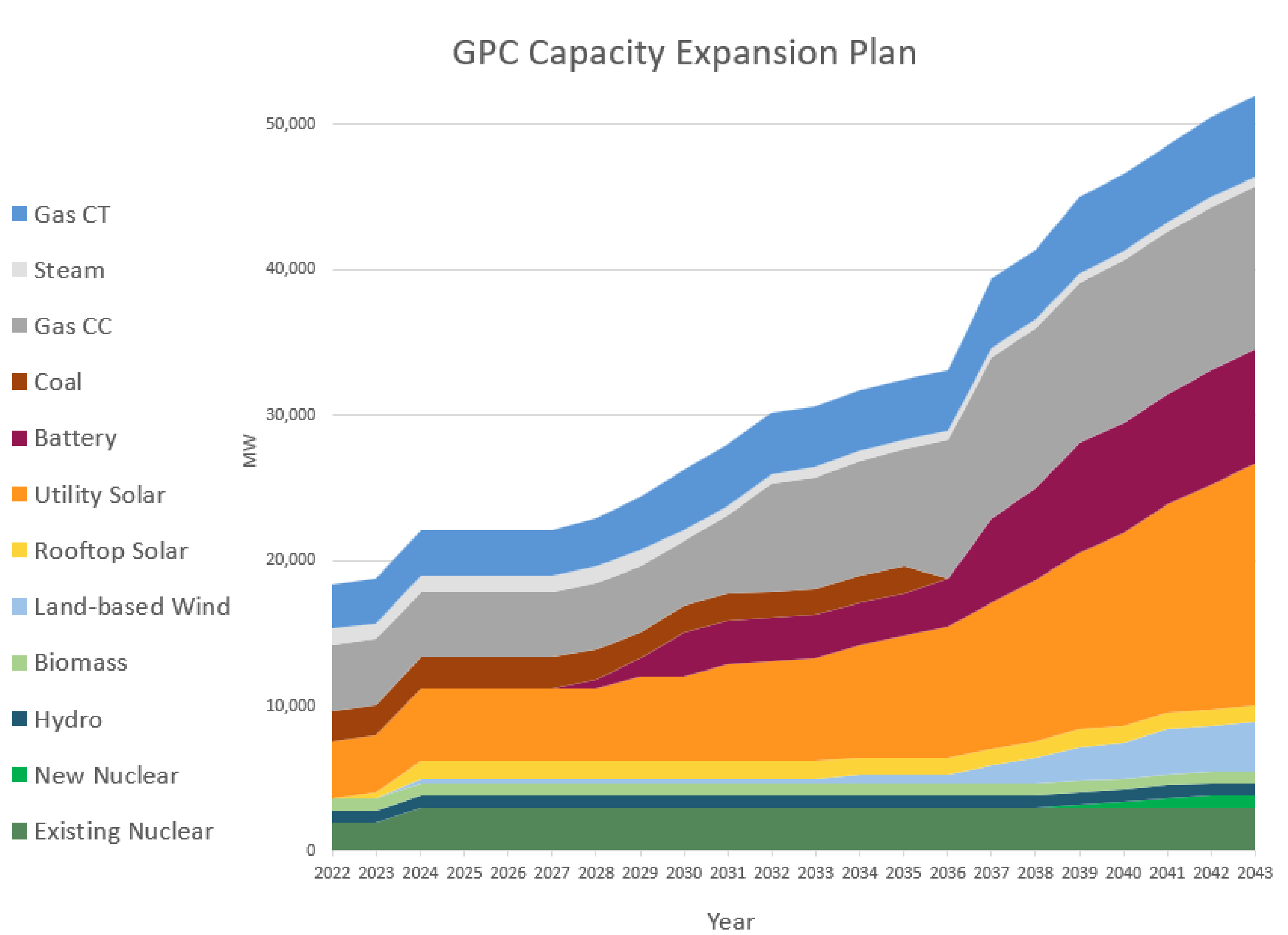
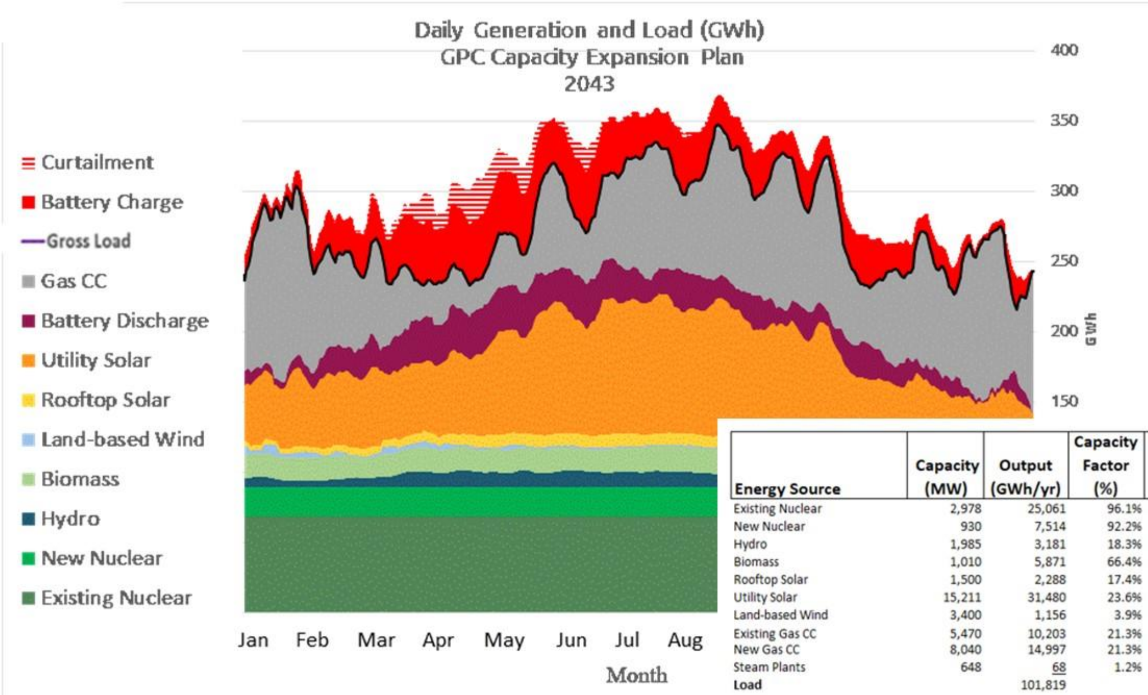


Figure 4 shows the sources that the grid will use for every day in 2043, assuming that Georgia Power's Capacity Expansion Plan goes into effect as projected. There will be a large contribution from solar and very small contribution from wind, large banks of batteries will help compensate for the intermittency of these renewable sources, and a small amount of additional nuclear power (much smaller than the current Vogtle plants) will be introduced. New gas plants will provide the variable dispatchable resources that the grid requires. Some of the solar is curtailed – that is, shut down or not used – during the period of low demand in the Spring.

Figure 4



Energy Source	Capacity (MW)	Output (GWh/yr)	Capacity Factor (%)	% Load
Existing Nuclear	2,978	25,061	96.1%	24.6%
New Nuclear	930	7,514	92.2%	7.4%
Hydro	1,985	3,181	18.3%	3.1%
Biomass	1,010	5,871	66.4%	5.8%
Rooftop Solar	1,500	2,288	17.4%	2.2%
Utility Solar	15,211	31,480	23.6%	30.9%
Land-based Wind	3,400	1,156	3.9%	1.1%
Existing Gas CC	5,470	10,203	21.3%	10.0%
New Gas CC	8,040	14,997	21.3%	14.7%
Steam Plants	648	68	1.2%	0.1%
Load		101,819		100.0%

Detailed quantitative results for the Capacity Expansion plan are shown in Table B-CEP.

Figure 5 shows how the hourly electricity load is met, from 8:00 am in the morning to the next day, for a mid-winter day (January 1) and a June day in 2043. On both days, there is enough sun to at least partially charge the batteries which then supply a portion of the load in the early evening but then run out. In June, there is so much sun, along with modest electric demand, that the batteries can be fully charged with excess solar energy that cannot be used, so it is dumped, or “curtailed”.

Figure 5 (January)

January 1-2, 2043

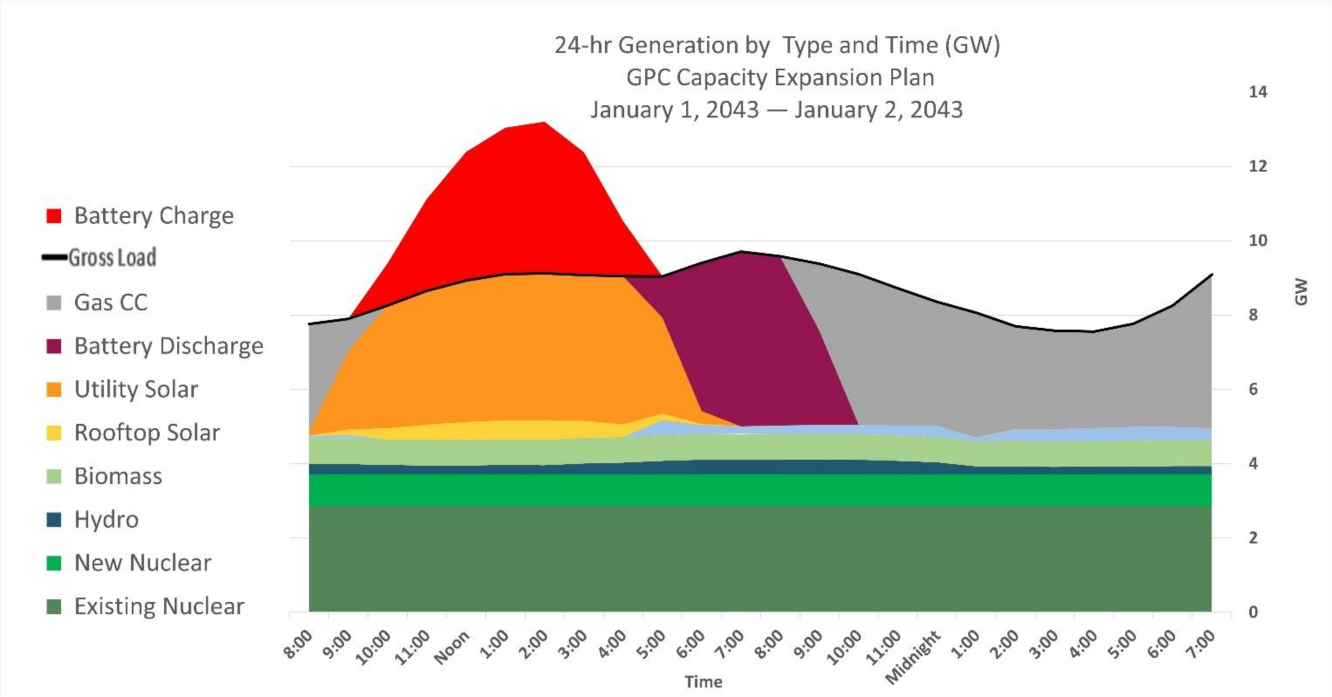
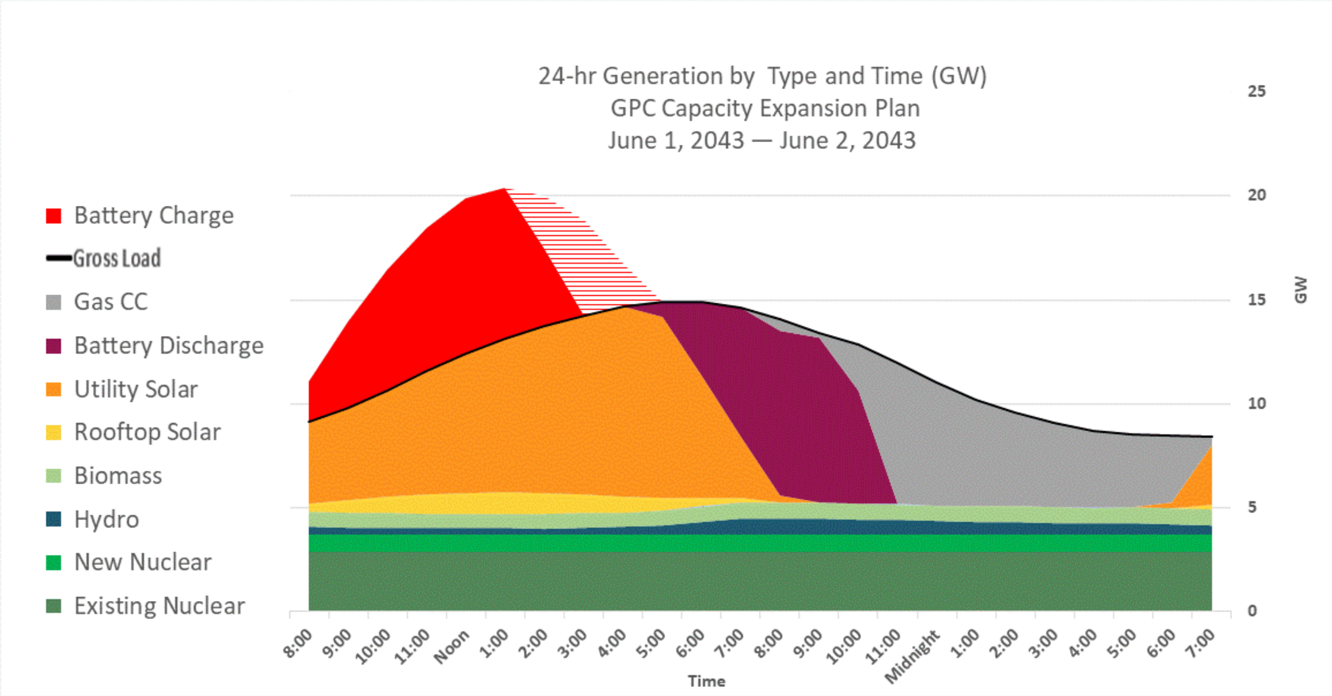


Figure 5 (June)

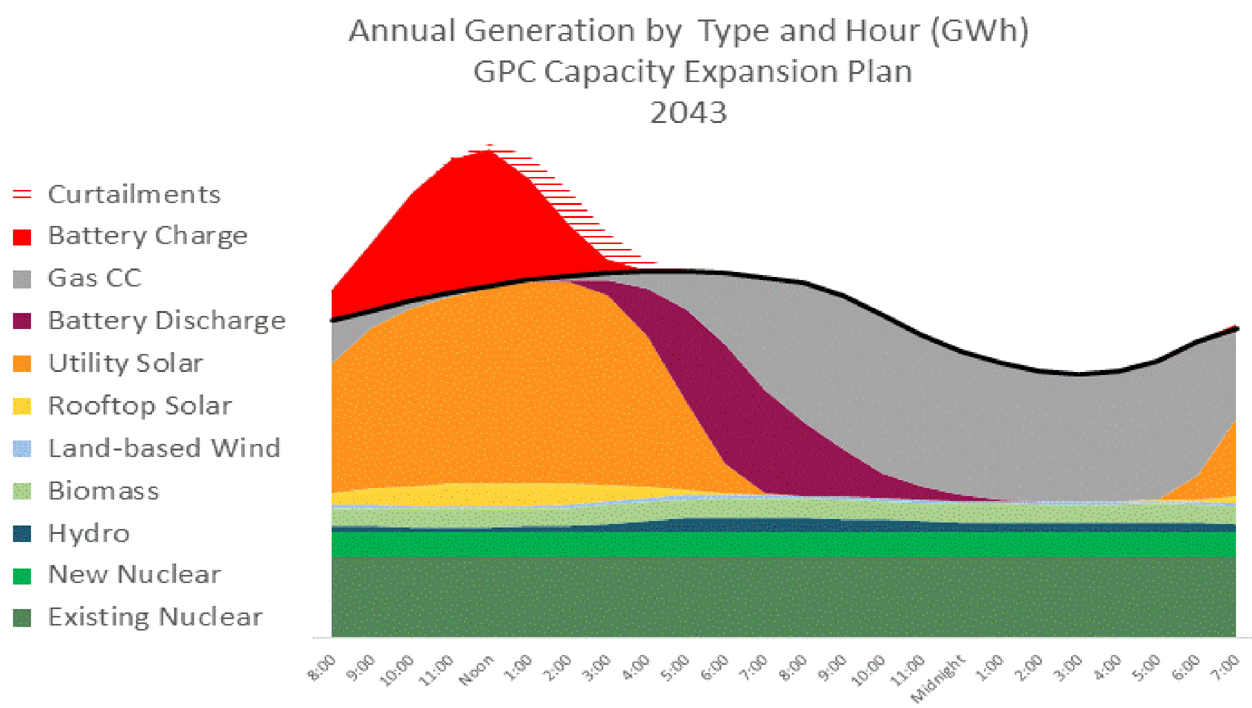
June 1-2, 2043



Still, in both cases, each evening the gas plants must be started up to keep the grid operating through the night. Figure 1d shows the total usage of each source for the entire year, by hour of the day (or this can be considered a picture of an average day in the year 2043). The sun, along with other clean sources, meets the electric demand during much of the day, and it even charges the batteries, but by early evening the sun is gone and the batteries are depleted, so the gas plants must be turned on to keep the lights (and every other piece of electrical equipment) on.

Figure 6

Annual Generation by Hour

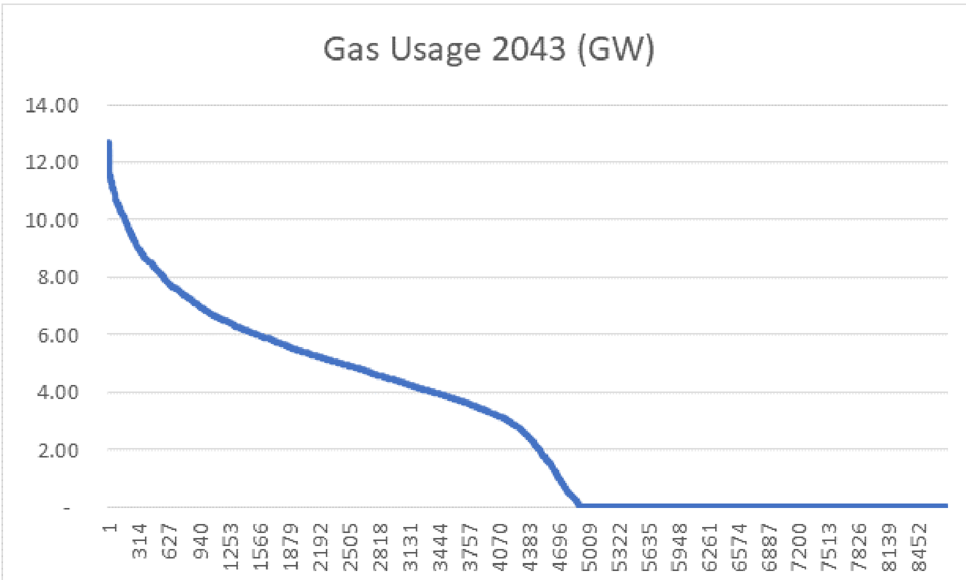


These visualizations tell a striking story. The 2043 total load has increased substantially from 2022, and solar power is providing much of the energy during the day. Solar capacity has increased from 3.6 GW to 15.2 GW. The load share carried by fossil fuels has declined from 62.8% to 24.8% while the output carried by the fossil fuels (just gas, which is the only fuel burned in this climate-sensitive situation) has declined by 50%. Nevertheless, gas is being burned much of every afternoon and evening throughout the year.

In fact, the gas plants have to operate for more than one-half of the 8760 hours in the year. Figure 7, the load-duration curve for natural gas-powered output, shows the number of hours each level of gas output is required.

Figure 7

Georgia Power Capacity Expansion Plan



The demand for electricity by 2043 is so great that even with this unprecedented expansion of solar and the introduction of wind power, these sources are unable to meet the demand. Solar, of course, is not available at night, so the dispatchable gas generators have to operate for much of the time. The batteries are charged during many days, but charging is limited during much of the winter. They discharge and are drained by early in the evening, and then the gas plants have to take over to keep power on through the night.

A cleaner, more reliable plan is possible using nuclear power

We have explored various alternate scenarios for the next twenty years which will reduce the burning of fossil fuels, leading to lower or no emission of greenhouse gases while costing no more and possibly less than Georgia Power's current Capacity Expansion Plan.

How can the burning of fossil fuels be reduced further? Instead of Georgia Power's plan to add to new gas capacity, they should be adding more nuclear facilities to their planned resource mix.

Nuclear plants require just a few acres of land and have negligible impact on the surrounding physical environment.[7] Comprehensive lifecycle analysis by the United Nations Economic Commission for Europe shows that, compared with other energy technologies, nuclear power has substantially lower ecosystem impacts when considering climate change, land use, and human health.[8] Most importantly, even before accounting for the cost of expanding transmission lines, the long life of nuclear facilities and the capital cost reductions likely to occur as plants are deployed across the U.S. imply that nuclear will be the least costly operation in the long run.

Energy + Environmental Economics, Inc. (E3), a San Francisco-based consulting firm, has assisted California, New York, and other states in analyzing their future decarbonized grids. In a study of decarbonization in the Pacific Northwest, E3 found an important role for nuclear reactors, observing that "…achieving 100% GHG reductions using only wind, solar, hydro, and energy storage is both impractical and prohibitively expensive."[9]

Nuclear power has been demonstrated to have the necessary capabilities, not only in the gigawatt-scale reactors now operating in Georgia and elsewhere, but in the smaller reactors now under commercial development and operating on submarines and ships for over sixty years. Once we recognize the potential role that nuclear power can play

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7 https://ourworldindata.org/land-use-per-energy-source

8 https://unece.org/sed/documents/2021/10/reports/life-cycle-assessment-electricity-generation-options

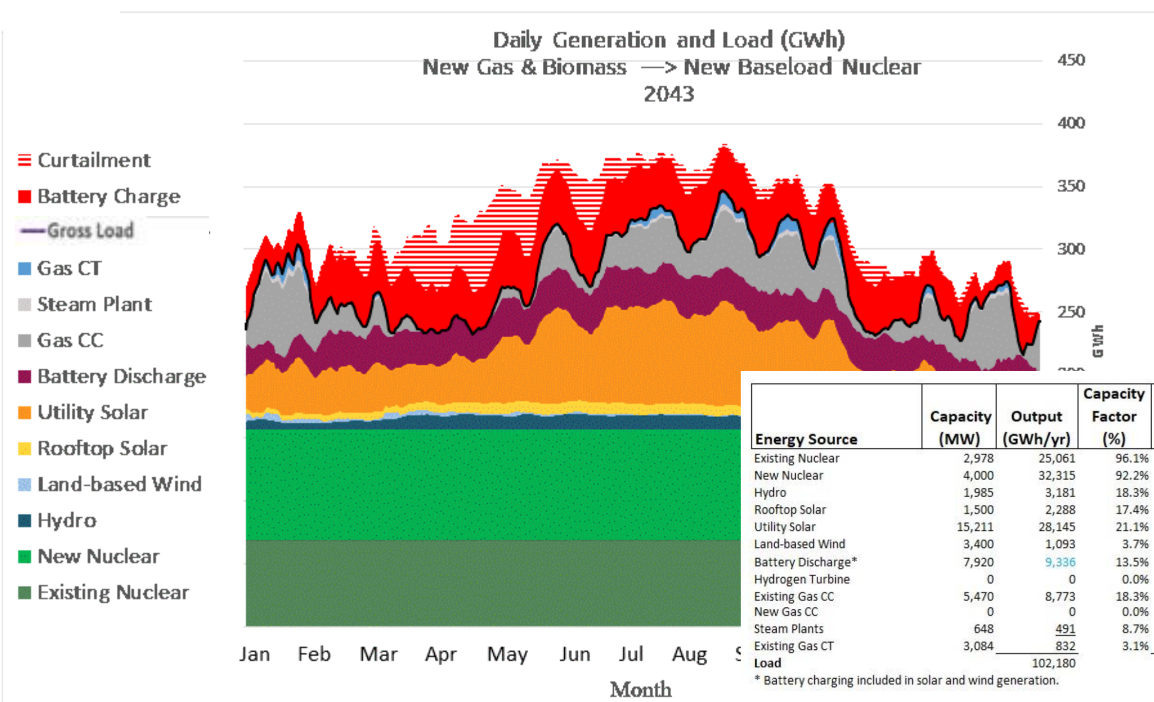
9 https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

and incorporate it into our vision of the future grid, we can create plans that will eliminate greenhouse gas emissions and reliably and affordably keep the lights on while conserving land and material resources. We present here five alternative plans for a future grid having these characteristics while successfully decarbonizing.

1– Replace new gas plants and the burning of biomass with new baseload nuclear

The first, most limited approach would replace the additional gas capacity that Georgia Power is planning with baseload nuclear power, similar to the AP-1000s at Vogtle 3 and 4. The burning of biomass (wood and municipal waste), which contributes substantial CO2 to the atmosphere, would also be ended. This would leave gas as the essential dispatchable source, but it would produce far smaller CO2 emissions than Georgia Power's current plan. The least-cost result requires the installation of 3.1GW of AP-1000-type light-water reactors. Annual usage in 2043 is shown Figure 8 and Table B-1.

Figure 8



Energy Source	Capacity (MW)	Output (GWh/yr)	Capacity Factor (%)	% Load
Existing Nuclear	2,978	25,061	96.1%	24.5%
New Nuclear	4,000	32,315	92.2%	31.6%
Hydro	1,985	3,181	18.3%	3.1%
Rooftop Solar	1,500	2,288	17.4%	2.2%
Utility Solar	15,211	28,145	21.1%	27.5%
Land-based Wind	3,400	1,093	3.7%	1.1%
Battery Discharge*	7,920	9,336	13.5%	9.1%
Hydrogen Turbine	0	0	0.0%	0.0%
Existing Gas CC	5,470	8,773	18.3%	8.6%
New Gas CC	0	0	0.0%	0.0%
Steam Plants	648	491	8.7%	0.5%
Existing Gas CT	3,084	832	3.1%	0.8%
Load		102,180		100.0%

* Battery charging included in solar and wind generation.

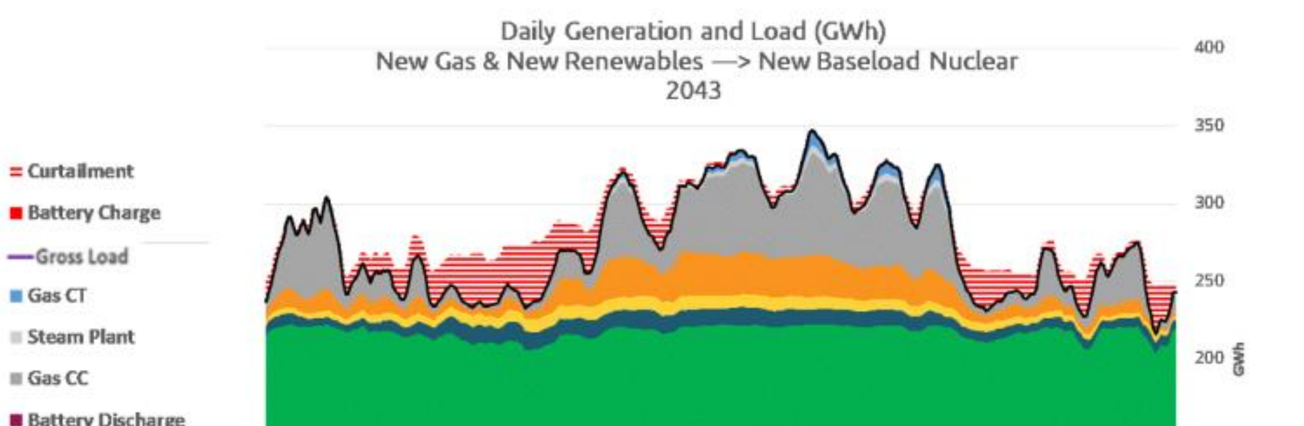
This plan is forecast to cost about the same as Georgia Power's current plan, but it will have substantially lower greenhouse gas emissions. (See cost and emission discussion below.)

2 – Replace new gas plants and new renewables with new baseload nuclear facilities

Instead of adding large numbers of solar panels and wind turbines and accompanying storage batteries, as Georgia Power is now planning, this alternative would replace these with 6 GW of new baseload nuclear, similar to Scenario 1. These renewable sources are non-dispatchable and intermittent and so must be accompanied by large banks of batteries to smooth out their intermittency. They also require wide swaths of land across the state, far more than the modest footprint of the nuclear facilities that would replace them.

The result is shown in Figure 9 and Table B-2. Gas is still providing the essential dispatchable resource the grid needs to maintain reliability.

Figure 9



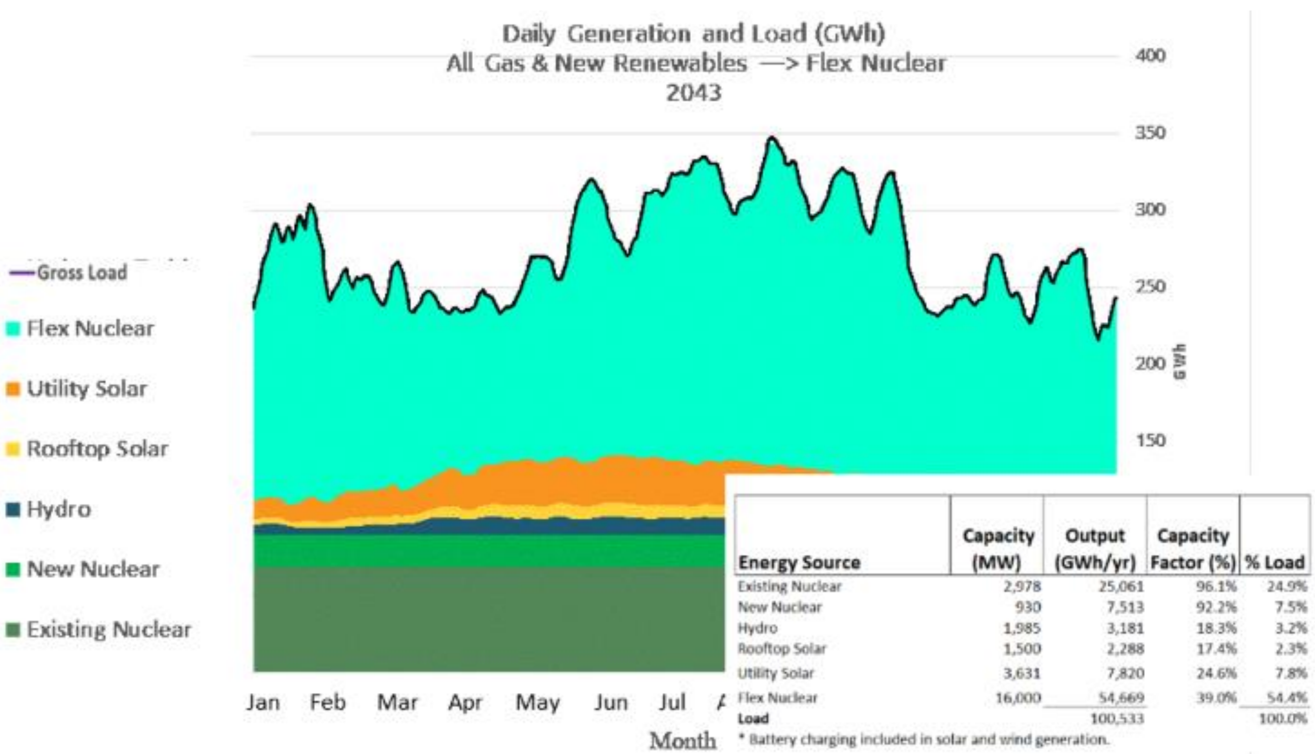
Energy Source	Capacity (MW)	Output (GWh/yr)	Capacity Factor (%)	% Load
Existing Nuclear	2,978	25,061	96.1%	24.9%
New Nuclear	6,930	54,341	89.5%	54.0%
Hydro	1,985	3,181	18.3%	3.2%
Rooftop Solar	1,500	2,288	17.4%	2.3%
Utility Solar	3,631	5,150	16.2%	5.1%
Existing Gas CC	5,470	9,729	20.3%	9.7%
Steam Plants	648	396	7.0%	0.4%
Existing Gas CT	3,084	467	1.7%	0.5%
Load		100,612		100.0%

* Battery charging included in solar and wind generation.

3 – Replace all gas plants and new renewables with dispatchable nuclear facilities

A more comprehensive plan would replace all gas plants, both those that exist and the planned new ones, with dispatchable nuclear facilities (here referred to as "flex nuclear"). As noted earlier, all modern nuclear plants can, to some extent, be load-following or dispatchable. However, we model nuclear plants as being of two distinct types, one baseload/always-one, the other dispatchable/responsive to demand. We model dispatchable facilities by using Terrapower's Natrium system, a nuclear reactor with large thermal storage that allows them to replace gas plants. The lowest-cost plan of this type requires 13.5 GW of nuclear capacity and is shown in Figure 10 and Table B-3. Unlike the previous scenarios, it produces no greenhouse gases, but it is very expensive because the full capacity of the nuclear plants is seldom used (low capacity factor).

Figure 10



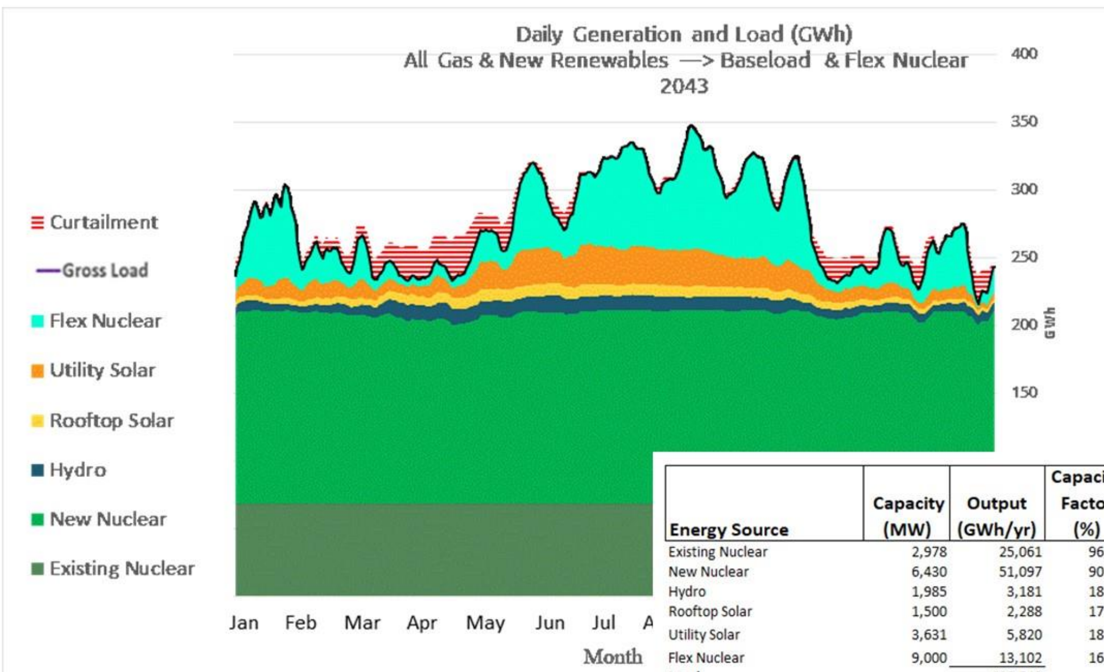
Energy Source	Capacity (MW)	Output (GWh/yr)	Capacity Factor (%)	% Load
Existing Nuclear	2,978	25,061	96.1%	24.9%
New Nuclear	930	7,513	92.2%	7.5%
Hydro	1,985	3,181	18.3%	3.2%
Rooftop Solar	1,500	2,288	17.4%	2.3%
Utility Solar	3,631	7,820	24.6%	7.8%
Flex Nuclear	16,000	54,669	39.0%	54.4%
Load		100,533		100.0%

* Battery charging included in solar and wind generation.

4 – Replace all gas plants and new renewables with a combination of baseload and flex (dispatchable) nuclear facilities

Here we combine the two previous approaches to obtain a more cost-effective carbon-free scenario in which 5.5 GW of new baseload nuclear together with 9 GW of flex nuclear would replace all the gas plants. The result is shown in Figure 11 and Table B-5. The flex nuclear is larger than might be expected because there are a few hours during mid-summer when large amounts of power are needed, and it is the only dispatchable source available to meet this short-term need.

Figure 11



Energy Source	Capacity (MW)	Output (GWh/yr)	Capacity Factor (%)	% Load
Existing Nuclear	2,978	25,061	96.1%	24.9%
New Nuclear	6,430	51,097	90.7%	50.8%
Hydro	1,985	3,181	18.3%	3.2%
Rooftop Solar	1,500	2,288	17.4%	2.3%
Utility Solar	3,631	5,820	18.3%	5.8%
Flex Nuclear	9,000	13,102	16.6%	13.0%
Load		100,549		100.0%

* Battery charging included in solar and wind generation.

This approach has lower costs than the all-flex nuclear plan but still requires a large flex nuclear component for the few evening hours in the summer when demand is high. (See cost discussion below.)

5 – Remove new gas and new renewables and add baseload nuclear and replace natural gas with hydrogen as the fuel for existing gas plants

A final option we examine uses baseload nuclear to replace the new gas plants and renewables in Georgia Power's plan, but it keeps the existing gas plants. However, it uses "clean hydrogen" as their fuel instead of natural gas, a fossil fuel. By "clean hydrogen," we mean hydrogen produced in a manner that does not generate any greenhouse gases. Nuclear power can be used to produce hydrogen by combining the heat and electricity generated with a reactor to split water molecules and extract the hydrogen. The hydrogen can then be burned in a suitably converted gas turbine. This alternative to using flex nuclear is more cost-effective because the reactors producing the hydrogen can run full-time, the most efficient way to operate a nuclear reactor, rather than with the reduced capacity factor found with the scenarios using flex nuclear.

The Federal Government is putting substantial funds into an effort to reduce the cost of "clean hydrogen" to the point where it will be competitive with natural gas. The first DOE Energy Earthshot was launched in 2021 and seeks to reduce the cost of clean hydrogen to $1 per kilogram within ten years. In our analysis, we assume this goal will be met. If it is, the cost of electricity from these plants would be about what it is today. In this scenario, the hydrogen generates 13,107 GWh of electricity each year could be produced by 3.7 GW of nuclear power, assuming a 40% "round-trip" power->hydrogen->power efficiency of producing hydrogen and using it to generate electricity in combined-cycle gas turbines.[10,11]

The results for this option are shown in Figure 12 and Table B-5.

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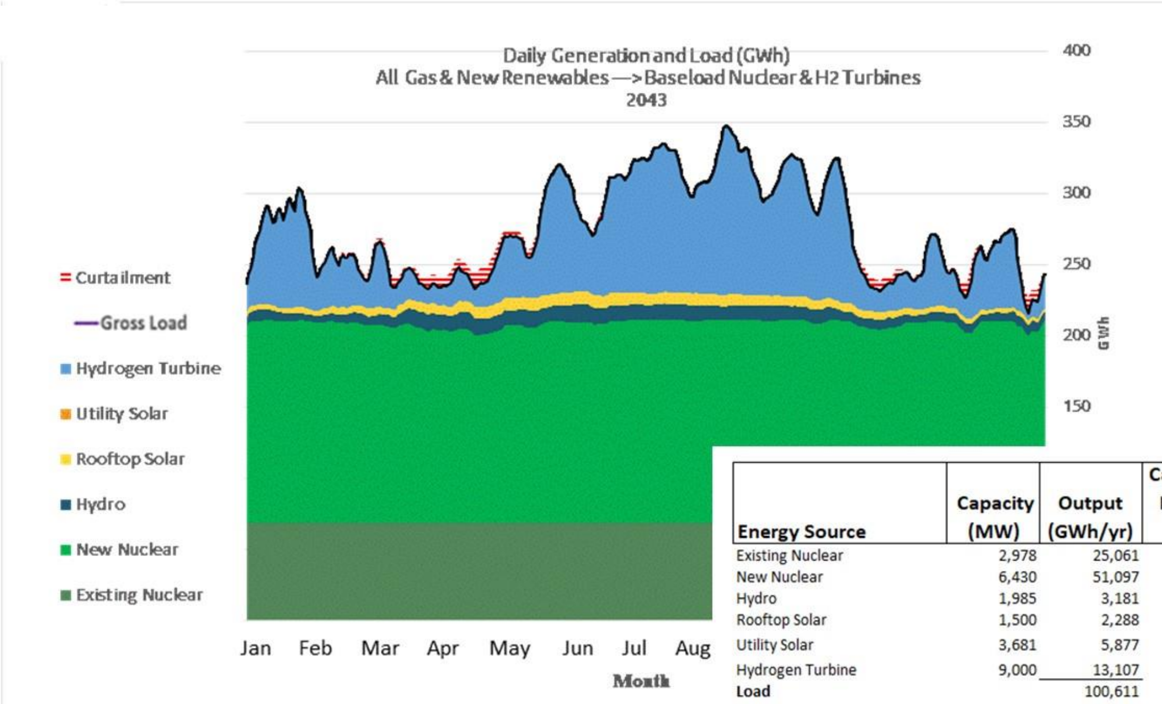
[10] https://www.sciencedirect.com/science/article/pii/S1040619021001330

[11] Another option to produce hydrogen is using renewable-generated electricity. Supplying sufficient energy to produce the required hydrogen would necessitate a doubling in the number of solar and wind installations envisioned in Georgia Power's Capacity Expansion Plan.

Figure 12



Energy Source	Capacity (MW)	Output (GWh/yr)	Capacity Factor (%)	% Load
Existing Nuclear	2,978	25,061	96.1%	24.9%
New Nuclear	6,430	51,097	90.7%	50.8%
Hydro	1,985	3,181	18.3%	3.2%
Rooftop Solar	1,500	2,288	17.4%	2.3%
Utility Solar	3,681	5,877	18.2%	5.8%
Hydrogen Turbine	9,000	13,107	16.6%	13.0%
Load		100,611		100.0%

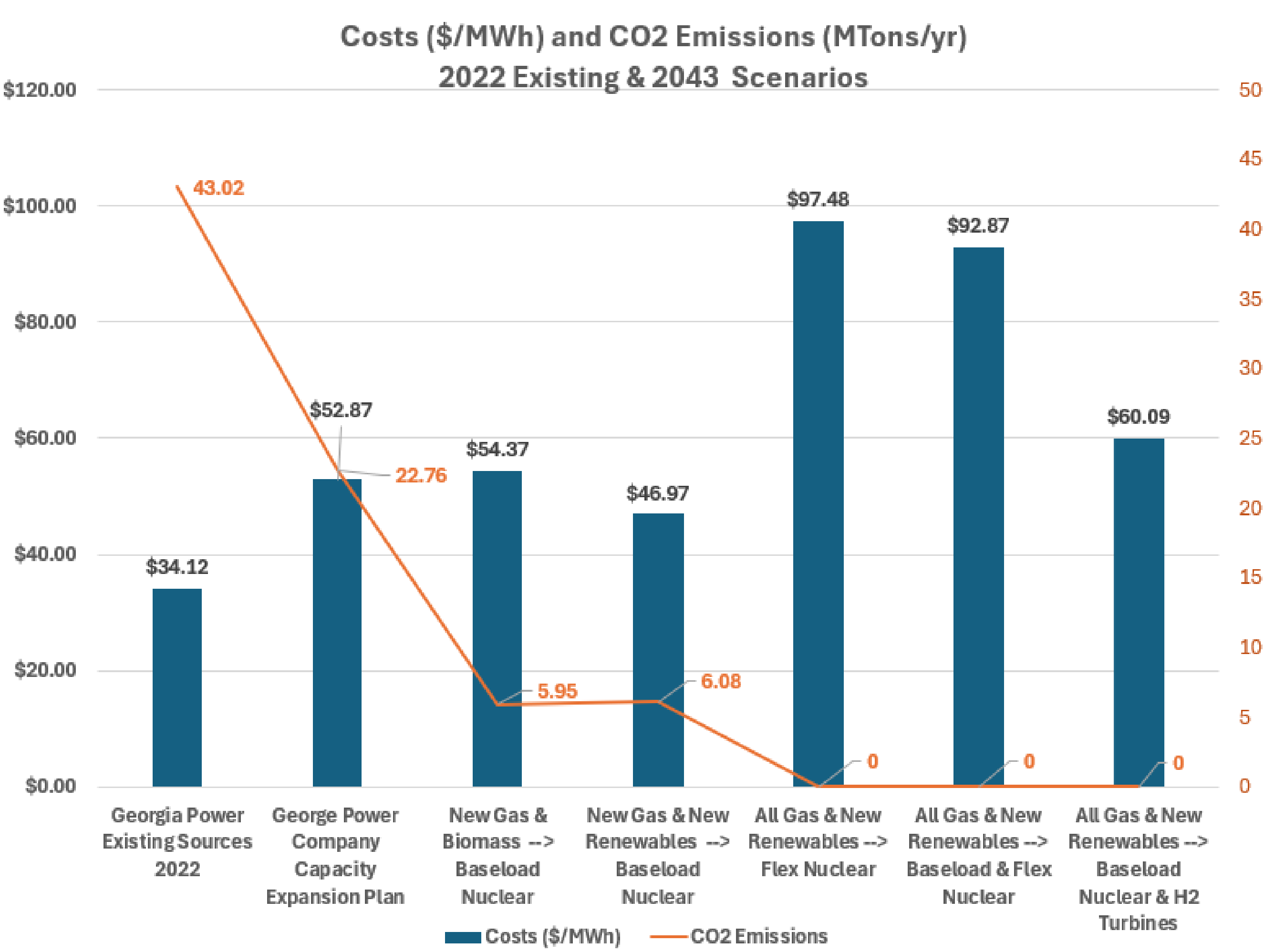
* Battery charging included in solar and wind generation.

What will these options cost, and how much would they reduce emissions?

The costs and [CO2 emissions][12] foe each of these options are shown in detail in the tables in Appendix B. Here they are gathered into a single figure:

[12]https://www.netl.doe.gov/projects/files/LifeCycleAnalysisofNaturalGasExtractionandPowerGenerationUS2020EmissionsProfile_121724.pdf

Figure 13



These dollar figures are the cost of producing electricity, the wholesale cost of electricity (in constant dollars) at the point where power enters the grid. Average residential electric rates in Georgia are about $158/MWh, much higher than the costs shown here because they include the cost of (long-range) transmission and (short-range) distribution.

The replacement of the new gas plants with nuclear increases the cost by an amount that is about 25% of the residential cost. The hydrogen option barely costs more than the current plan, provided the Federal Government reaches its goal of $1/kg for hydrogen.

This report uses projected energy costs from the Annual Technology Baseline (ATB) prepared by the National Renewable Energy Laboratory. These project that solar, wind, batteries, and nuclear costs will decline by about 50% in the next twenty years. However, future prices are uncertain, and the generation costs shown in Appendix B should, in our view, be treated as only illustrative. The reader can use the spreadsheet entitled *Georgia Generation Costs and Energy Prices* (available at http://bit.ly/3Ph4qlc) to examine how generation costs in each of our scenarios are affected by different prices for solar, wind, batteries, and nuclear facilities.

A large dispatchable emission-free resource is essential. What should it be?

Our results show that decarbonization of the grid requires a large-capacity dispatchable emission-free resource running a significant part of the year. We suggest that nuclear power should serve this role. Are there other choices?

A number of other approaches have been offered:

- Fuel cells or gas turbines powered by “green hydrogen”: Hydrogen fuel cells or combustion power plants similar to those now burning fossil fuels could run on “green hydrogen” produced in electrolyzers powered by renewable energy, as Georgia Power has suggested. However, such a plan requires the creation of an expensive infrastructure to transport and store the hydrogen, as well as a buildout of additional costly, land-hungry solar and wind facilities to power the hydrolysis plants that produce the hydrogen. Using hydrogen for energy storage is challenged, also, by the fact that the overall efficiency of this process is just 40%. This means that more than twice as much energy must be added as will be generated by the turbines, with a commensurate drain on material resources, land, and societal wealth.
- Long-duration storage: Currently no realistic scalable form of such storage exists. If it did, it, too, would require a vast expansion of solar and wind generating capacity to charge whatever storage medium is used.

- Carbon capture and storage (CCS) attached to gas-fired power plants: This technology exists only on an experimental basis. It would add substantial cost to the power plant it was attached to, and there would be significant upstream leakage of greenhouse gases and other pollutants to the environment. The captured CO_2 would have to be disposed of, presumably underground, adding additional cost as well as potential environmental damage.
- Alternate nuclear options: Other ways of using nuclear energy deserve consideration. Nuclear reactors, like most energy sources, are most cost-efficient when they run most of the time to meet demand. We found that the dispatchable source, while essential, would be operating at just partial capacity for most of the year. A more cost-effective plan might use a smaller number of reactors running continuously to produce carbon-neutral synthetic fuels like natural gas which could then be used in the grid.[13,14] A full analysis of the cost and suitability of this options is beyond the scope of this report, but it deserves serious study.

Limitations of the model/future research

The model we are using, while it shows the principal properties and requirements for the future grid, has significant limitations as well. Among these are:

1. Simplified view of in-state transmission: This model treats the state's grid as a single region without transmission constraints, whereas there are likely to be significant barriers to the flow of power between areas of any large geographic area. The model also does not reflect transmission upgrade costs that will occur with economy-wide electrification, irrespective of the chosen technologies. However, transmission upgrade challenges will be larger, both politically and financially, if large amounts of widespread intermittent sources need to be integrated. A group at Cornell working with Prof. C.

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[13] Operational Energy from Seawater, US Naval Research Laboratory. https://www.hydrogen.energy.gov/pdfs/review18/ia018_willauer_2018_p.pdf

[14] https://www.thechemicalengineer.com/features/fuelling-the-world-with-biomass/

Lindsay Anderson has explored the difficulties to be encountered if large amounts of distributed sources were to be introduced into New York State's grid.[15]

2. Absence of reserves: Our model does not reflect the reserve requirements imposed by state and federal law.

3. Improved dispatchable resource design: The chosen dispatchable resource in our model drops from 500 MW to 345 MW capacity when its thermal storage is depleted. Having a resource with its maximum capacity always available, perhaps accompanied by batteries, might be more cost-effective than the example we have used.

Conclusion

Georgia will benefit from the deployment of additional nuclear power in the coming decades. Using an hour-by-hour modeling tool, we have demonstrated that nuclear power —operating as a constant baseload and in a flexible, dispatchable mode running a large portion of the year — can achieve the goal of a reliable, zero-emission grid. Nuclear is the only such source likely to be available in this period. This combination of nuclear resources will be more cost-efficient and environmentally protective than any alternative relying upon intermittent weather-dependent sources.

[15] https://arxiv.org/abs/2307.15079

Appendix A: CACI Grid Model Methodology

The Georgia adaptation of the CACI Grid Model works as follows:

In this model, each type of energy source is dispatched hourly to address electric loads, taking account of the availability of all non-dispatchable generation before turning to costly dispatchable sources. Model inputs include hourly data for loads, solar generation, wind generation, hydro generation, and (if available) power exchange with other regions. The assumptions and methods used in the model are as follows:

Power generation is represented in these categories: behind the meter (BTM) and utility solar, land-based wind, hydroelectric, nuclear, battery storage, and a series of possible dispatchable sources. When the burning of fossil fuels is permitted, gas-fired combined-cycle and simple-cycle plants are included. Existing nameplate capacities are taken from Georgia Power publications, while actual output is based on 2022 data for calibration purposes.

Total system loads are estimated using 2022 data from Georgia Power. Projections of current demand, as well as the new demand from electric vehicles (EVs) and the electrification of buildings, are also drawn from Georgia Power.

Hourly generation from solar and land-based wind is scaled up based on the distribution of 2022 hourly output data for these sources. The maximum capacity of solar and wind facilities reflects the regional distribution of generators and the likelihood that they can operate at the same time. These values are different from nameplate capacity which represents the output of a single unit at a specified point. Maximum capacity is derived from evaluating actual generating data in 2022.

Capacity factors — the fraction of the potential output of a source that is actually produced during the year — are not assumed in this model but are calculated based upon the weather and the behavior of the grid.

The dispatchable emission-free resource (DEFR) utilized in these scenarios is modeled using the characteristics of the TerraPower Natrium small modular reactor.[16]

Battery storage is modeled by assuming the batteries are charged when there is more inflexible power from hydropower, nuclear, utility solar, and wind than is needed to meet demand. The dispatchable source is not used to charge the batteries. The batteries are discharged when the load on the grid is greater than can be provided by those ongoing non-dispatchable sources. The dispatchable sources are drawn upon only when batteries have been completely discharged.

Each source is dispatched in turn to meet the load, as follows: behind-the-meter solar is introduced first, leaving the remaining load to be served by the various sources connected to the grid. Existing nuclear plant output is added as "must-run" capacity. Hydroelectric generation is added. Output from utility solar plus land-based wind are then added, taking into account their hourly variations as described above.

A portion of the maximum annual load is set aside for system control by gas combined-cycle plants or battery discharge, representing spinning reserve and other ancillary grid services. This is required even when there are curtailments of solar and wind generation.

When there is unmet load remaining after these non-dispatchable sources have been included, the batteries are called on to discharge up to their ability. If unmet load still remains, then the dispatchable sources are used to supply the remaining load. Then curtailments are assigned in random order to land-based wind and utility solar, but not to BTM solar, which is not controlled by the grid operator.

Imports and exports are not considered at this time, since data on them was not available. They can be included in the model when their nature and potential availability

[16] https://www.terrapower.com/our-work/natriumpower/

are known. Curtailments occur when total non-dispatchable generation exceeds the load required.

The model uses current dollars so that the effects of future inflation do not confuse the analysis. Costs of energy sources are estimated from a variety of data sources including DOE's Energy Information Administration and the "Moderate Costs" in the Annual Technology Baseline of the National Renewable Energy Laboratory. The prices used in the scenarios reported here are shown in Appendix B. The total generation cost of electricity is the weighted average of the cost of operating generation sources. The cost for each generation source includes fixed and variable operation and maintenance (O&M) cost, fuel cost, and capital recovery cost.

Appendix B: Data Sheets

Electricity Generation, Costs, and Emissions

Table B-Base

2022

Generation and Cost Summary — GPC Existing Sources — NREL Projected Cost — Year 2022

*Non-dispatchable**	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Existing Nuclear	1,960	16,494	96.1%	19.3%	$ 141	$ 3.70	$ 1.22	$ 4.09	$ 1.16	$ 10.17	-
New Nuclear	0	0	0.0%	0.0%	$ 5,663	$ -	$ -	$ -	$ -	$ -	-
Hydro	1,985	3,181	18.3%	3.7%		$ 27.32	$ 1.48			$ 28.80	-
Biomass	1,010	5,871	66.4%	6.9%		$ 22.64	$ 5.06	-	$ -	$ 27.70	8.81
Rooftop Solar	0	0	0.0%	0.0%	$ 1,373	$ 11.14	$ -	$ -	$ 49.50	$ 60.65	-
Utility Solar	3,631	7,820	24.6%	9.1%	$ 754	$ 6.50	$ -	$ -	$ 22.76	$ 29.26	-
Land-based Wind	0	0	0.0%	0.0%	$ 1,188	$ 74.14	$ -	$ -	$ 230.37	$ 304.52	-
Offshore Wind	0	0	0.0%	0.0%	$ 4,800	$ 17.43	$ -	$ -	$ 74.61	$ 92.03	-
Total	8,586	33,367	44.4%	38.9%		$ 9.94	$ 1.63	$ 2.02	$ 5.91	$ 19.50	

Dispatchable	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Battery Discharge	0	0	0.0%	0.0%	$ 1,140	$ -	$ -	$ -	$ -	$ -	-
Flex Nuclear	0	0	0.0%	0.0%	$ 5,480	$ -	$ -	$ 2.60	$ -	$ 2.60	-
Existing Gas CC	5,470	35,341	73.8%	41.3%	$ -	$2.26	$2.64	$35.00	$0.00	$39.90	19.44
New Gas CC	0	0	0.0%	0.0%	$ 1,485	$0.00	$0.00	$31.00	$0.00	$31.00	0.00
Hydrogen Turbine	0	0	0.0%	0.0%	$ 1,257	$0.00	$0.00	$33.00	$0.00	$33.00	0.00
Coal	3,848	11,810	35.0%	13.8%	$ -	$5.50	$4.71	$54.00	$0.00	$64.21	10.39
Steam Plants	1,108	2,758	28.4%	3.2%		$0.00	$2.64	$35.00	$0.00	$37.64	2.34
Existing Gas CT	3,084	2,397	8.9%	2.8%	$ -	$21.72	$4.71	$54.00	$0.00	$80.43	2.04
New Gas CT	0	0	0.0%	0.0%	$ 979	$0.00	$0.00	$49.00	$0.00	$49.00	0.00
Total	13,510	52,306	44.2%	61.1%		$ 3.76	$ 3.20	$ 40.16	$ -	$ 47.13	43.02

Total In-State Generation	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load		Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)
Total	22,097	85,673	44.3%	100.0%		$ 6.17	$ 2.59	$ 25.31	$ 2.30	$ 34.12

Regional Purchases		Generation (GWh/yr)		% Total Load
Imports		-		0.0%

	GWh/yr	% Total Load	% of Grid Renewables
Curtailments	0	0.0%	0.0%
Net Battery Load	0	0.0%	

Total Load (GWh/yr)	85,673

* Battery charging included in solar and wind generation.

Table B-CEP

Georgia Power's Capacity Expansion plan

Generation and Cost Summary | GPC Capacity Expansion Plan | NREL Projected Cost | Year 2043

*Non-dispatchable**	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Existing Nuclear	2,978	25,061	96.1%	24.6%	$ 141	$ 3.70	$ 1.22	$ 4.09	$ 1.16	$ 10.17	-
New Nuclear	930	7,514	92.2%	7.4%	$ 5,663	$ 21.66	$ 0.97	$ 3.40	$ 49.07	$ 75.10	-
Hydro	1,985	3,181	18.3%	3.1%		$ 27.32	$ 1.48			$ 28.80	-
Biomass	1,010	5,871	66.4%	5.8%		$ 22.64	$ 5.06	-	$ -	$ 27.70	8.81
Rooftop Solar	1,500	2,288	17.4%	2.2%	$ 1,373	$ 11.14	$ -	$ -	$ 49.50	$ 60.65	-
Utility Solar	15,211	31,480	23.6%	30.9%	$ 754	$ 6.76	$ -	$ -	$ 23.68	$ 30.45	-
Land-based Wind	3,400	1,156	3.9%	1.1%	$ 1,188	$ 76.49	$ -	$ -	$ 237.67	$ 314.16	-
Offshore Wind	0	0	0.0%	0.0%	$ 4,800	$ 17.76	$ -	$ -	$ 76.04	$ 93.80	-
Total	27,014	76,551	32.3%	75.2%		$ 10.48	$ 0.94	$ 1.67	$ 20.00	$ 33.10	

Dispatchable	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Battery Discharge	7,920	7,083	10.2%	7.0%	$ 1,140	$ 27.95	$ -	$ -	$ 98.16	$ 126.11	-
Flex Nuclear	0	0	0.0%	0.0%	$ 5,480	$ -	$ -	$ 2.60	$ -	$ 2.60	-
Existing Gas CC	5,470	10,203	21.3%	10.0%	$ -	$7.83	$2.64	$35.00	$0.00	$45.47	5.61
New Gas CC	8,040	14,997	21.3%	14.7%	$ 1,485	$10.72	$2.00	$31.00	$55.73	$99.45	8.25
Hydrogen Turbine	0	0	0.0%	0.0%	$ 1,257	$0.00	$0.00	$33.00	$0.00	$33.00	0.00
Coal	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$0.00	$0.00	$0.00	0.00
Steam Plants	648	68	1.2%	0.1%		$10.72	$2.64	$35.00	$0.00	$48.36	0.06
Existing Gas CT	3,084	23	0.1%	0.0%	$ -	$2,285.54	$4.71	$54.00	$0.00	$2,344.25	0.02
New Gas CT	2,490	18	0.1%	0.0%	$ 979	$988.46	$4.71	$49.00	$9,279.36	$10,321.53	0.02
Total	27,652	25,309	10.4%	24.8%		$ 15.73	$ 1.77	$ 25.52	$ 52.53	$ 122.29	22.76

Total In-State Generation	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load		Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)
Total	54,667	101,860	21.3%	100.0%		$ 11.78	$ 1.15	$ 7.60	$ 28.08	$ 52.87

Regional Purchases		Generation (GWh/yr)		% Total Load
Imports		-		0.0%

	GWh/yr	% Total Load	% of Grid Renewables
Curtailments	1,319	1.3%	3.0%
Net Battery Load	1,252	1.2%	

Total Load (GWh/yr)	101,860

* Battery charging included in solar and wind generation.

Figure B-1

New Gas & Biomass → New Baseload Nuclear

Generation and Cost Summary — New Gas & Biomass —> New Baseload Nuclear — NREL Projected Costs — Year 2043

*Non-dispatchable**	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Existing Nuclear	2,978	25,061	96.1%	24.5%	$ 141	$ 3.70	$ 1.22	$ 4.09	$ 1.16	$ 10.17	-
New Nuclear	4,000	32,315	92.2%	31.6%	$ 5,663	$ 21.66	$ 0.97	$ 3.40	$ 49.07	$ 75.10	-
Hydro	1,985	3,181	18.3%	3.1%		$ 27.32	$ 1.48			$ 28.80	-
Biomass	-	-	0.0%	0.0%		$ -	$ 5.06	-	$ -	$ 5.06	0.00
Rooftop Solar	1,500	2,288	17.4%	2.2%	$ 1,373	$ 11.14	$ -	$ -	$ 49.50	$ 60.65	-
Utility Solar	15,211	28,145	21.1%	27.5%	$ 754	$ 7.57	$ -	$ -	$ 26.49	$ 34.05	-
Land-based Wind	3,400	1,093	3.7%	1.1%	$ 1,188	$ 80.85	$ -	$ -	$ 251.20	$ 332.05	-
Offshore Wind	0	0	0.0%	0.0%	$ 4,800	$ 18.37	$ -	$ -	$ 78.63	$ 97.00	-
Total	29,074	92,084	36.2%	90.1%		$ 13.10	$ 0.72	$ 2.31	$ 29.84	$ 45.98	

Dispatchable	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Battery Discharge	7,920	9,336	13.5%	9.1%	$ 1,140	$ 21.21	$ -	$ -	$ 74.46	$ 95.67	-
Flex Nuclear	0	0	0.0%	0.0%	$ 5,480	$ -	$ -	$ 2.60	$ -	$ 2.60	-
Existing Gas CC	5,470	8,773	18.3%	8.6%	$ -	$9.10	$2.64	$35.00	$0.00	$46.75	4.83
New Gas CC	0	0	0.0%	0.0%	$ 1,485	$0.00	$0.00	$31.00	$0.00	$31.00	0.00
Hydrogen Turbine	0	0	0.0%	0.0%	$ 1,257	$0.00	$0.00	$33.00	$0.00	$33.00	0.00
Coal	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$0.00	$0.00	$0.00	0.00
Steam Plants	648	491	8.7%	0.5%		$0.00	$2.64	$35.00	$0.00	$37.64	0.42
Existing Gas CT	3,084	832	3.1%	0.8%	$ -	$62.60	$4.71	$54.00	$0.00	$121.31	0.71
New Gas CT	0	0	0.0%	0.0%	$ 979	$0.00	$0.00	$49.00	$0.00	$49.00	0.00
Total	17,122	10,096	6.7%	9.9%		$ 16.98	$ 1.46	$ 19.00	$ 35.78	$ 140.92	5.95

Total In-State Generation	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load		Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)
Total	46,196	102,180	25.2%	100.0%		$ 13.49	$ 0.80	$ 3.96	$ 30.43	$ 54.37

Regional Purchases		Generation (GWh/yr)		% Total Load
Imports		-		0.0%
Total Load (GWh/yr)		102,180		

	GWh/yr	% Total Load	% of Grid Renewables
Curtailments	4,715	4.6%	13.6%
Net Battery Load	1,651	1.6%	

* Battery charging included in solar and wind generation.

Table B-2

New Gas & New Renewables → New Baseload Nuclear

Generation and Cost Summary | New Gas & New Renewables —> New Baseload Nuclear | NREL Projected Costs | Year 2043

*Non-dispatchable**	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Existing Nuclear	2,978	25,061	96.1%	24.9%	$ 141	$ 3.70	$ 1.22	$ 4.09	$ 1.16	$ 10.17	-
New Nuclear	6,930	54,341	89.5%	54.0%	$ 5,663	$ 22.32	$ 0.97	$ 3.40	$ 50.55	$ 77.24	-
Hydro	1,985	3,181	18.3%	3.2%		$ 27.32	$ 1.48			$ 28.80	-
Biomass	-	-	0.0%	0.0%		$ -	$ 5.06	-	$ -	$ 5.06	0.00
Rooftop Solar	1,500	2,288	17.4%	2.3%	$ 1,373	$ 11.14	$ -	$ -	$ 49.50	$ 60.65	-
Utility Solar	3,631	5,150	16.2%	5.1%	$ 754	$ 9.87	$ -	$ -	$ 34.55	$ 44.42	-
Land-based Wind	-	-	0.0%	0.0%	$ 1,188	$ -	$ -	$ -	$ -	$ -	-
Offshore Wind	0	0	0.0%	0.0%	$ 4,800	$ 25.90	$ -	$ -	$ 110.90	$ 136.80	-
Total	17,024	90,022	60.4%	89.5%		$ 16.32	$ 0.98	$ 3.19	$ 34.07	$ 54.56	

Dispatchable	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Battery Discharge	0	0	0.0%	0.0%	$ 1,140	$ -	$ -	$ -	$ -	$ -	-
Flex Nuclear	0	0	0.0%	0.0%	$ 5,480	$ -	$ -	$ 2.60	$ -	$ 2.60	-
Existing Gas CC	5,470	9,729	20.3%	9.7%	$ -	$8.21	$2.64	$35.00	$0.00	$45.85	5.35
New Gas CC	0	0	0.0%	0.0%	$ 1,485	$0.00	$0.00	$31.00	$0.00	$31.00	0.00
Hydrogen Turbine	0	0	0.0%	0.0%	$ 1,257	$0.00	$0.00	$33.00	$0.00	$33.00	0.00
Coal	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$0.00	$0.00	$0.00	0.00
Steam Plants	648	396	7.0%	0.4%		$0.00	$2.64	$35.00	$0.00	$37.64	0.34
Existing Gas CT	3,084	467	1.7%	0.5%	$ -	$111.56	$4.71	$54.00	$0.00	$170.27	0.40
New Gas CT	0	0	0.0%	0.0%	$ 979	$0.00	$0.00	$49.00	$0.00	$49.00	0.00
Total	9,202	10,591	13.1%	10.5%		$ 12.46	$ 2.73	$ 35.84	$ -	$ 51.03	6.08

Total In-State Generation	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load		Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)
Total	26,226	100,612	43.8%	100.0%		$ 15.91	$ 1.16	$ 6.63	$ 30.49	$ 53.40

Regional Purchases		Generation (GWh/yr)		% Total Load
Imports		-		0.0%

	GWh/yr	% Total Load	% of Grid Renewables
Curtailments	4,316	4.3%	40.6%
Net Battery Load	0	0.0%	

Total Load (GWh/yr)	100,612

* Battery charging included in solar and wind generation.

Table B-3

All Gas & New Renewables → Flex Nuclear

Generation and Cost Summary — All Gas & New Renewables —> Flex Nuclear — NREL Projected Cost — Year 2043

*Non-dispatchable**	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Existing Nuclear	2,978	25,061	96.1%	24.9%	$ 141	$ 3.70	$ 1.22	$ 4.09	$ 1.16	$ 10.17	-
New Nuclear	930	7,513	92.2%	7.5%	$ 5,663	$ 21.66	$ 0.97	$ 3.40	$ 49.07	$ 75.11	-
Hydro	1,985	3,181	18.3%	3.2%		$ 27.32	$ 1.48			$ 28.80	-
Biomass	-	-	0.0%	0.0%		$ -	$ 5.06		$ -	$ 5.06	0.00
Rooftop Solar	1,500	2,288	17.4%	2.3%	$ 1,373	$ 11.14	$ -	$ -	$ 49.50	$ 60.65	-
Utility Solar	3,631	7,820	24.6%	7.8%	$ 754	$ 6.50	$ -	$ -	$ 22.76	$ 29.26	-
Land-based Wind	-	-	0.0%	0.0%	$ 1,188	$ -	$ -	$ -	$ -	$ -	-
Offshore Wind	0	0	0.0%	0.0%	$ 4,800	$ 17.44	$ -	$ -	$ 74.64	$ 92.08	-
Total	11,024	45,864	47.5%	45.6%		$ 9.13	$ 0.93	$ 2.79	$ 15.02	$ 27.87	

Dispatchable	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Battery Discharge	0	0	0.0%	0.0%	$ 1,140	$ -	$ -	$ -	$ -	$ -	-
Flex Nuclear	16,000	54,669	39.0%	54.4%	$ 5,480	$ 39.80	$ 1.20	$ 2.60	$ 112.27	$ 155.87	-
Existing Gas CC	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$35.00	$0.00	$35.00	0.00
New Gas CC	0	0	0.0%	0.0%	$ 1,485	$0.00	$0.00	$31.00	$0.00	$31.00	0.00
Hydrogen Turbine	0	0	0.0%	0.0%	$ 1,257	$0.00	$0.00	$33.00	$0.00	$33.00	0.00
Coal	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$0.00	$0.00	$0.00	0.00
Steam Plants	0	0	0.0%	0.0%		$0.00	$0.00	$35.00	$0.00	$35.00	0.00
Existing Gas CT	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$54.00	$0.00	$54.00	0.00
New Gas CT	0	0	0.0%	0.0%	$ 979	$0.00	$0.00	$49.00	$0.00	$49.00	0.00
Total	16,000	54,669	39.0%	54.4%		$ 39.80	$ 1.20	$ 2.60	$ 112.27	$ 155.87	0.00

Total In-State Generation	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load		Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)
Total	27,024	100,533	42.5%	100.0%		$ 25.81	$ 1.08	$ 2.69	$ 67.90	$ 97.48

Regional Purchases		Generation (GWh/yr)		% Total Load
Imports		-		0.0%

	GWh/yr	% Total Load	% of Grid Renewables
Curtailments	1	0.0%	0.0%
Net Battery Load	0	0.0%	

Total Load (GWh/yr)	100,533

* Battery charging included in solar and wind generation.

Table B-4

All Gas & New Renewables → Baseload & Flex Nuclear

Generation and Cost Summary | All Gas & New Renewables —> Baseload & Flex Nuclear | NREL Projected Cost | Year 2043

*Non-dispatchable**	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Existing Nuclear	2,978	25,061	96.1%	24.9%	$ 141	$ 3.70	$ 1.22	$ 4.09	$ 1.16	$ 10.17	-
New Nuclear	6,430	51,097	90.7%	50.8%	$ 5,663	$ 22.02	$ 0.97	$ 3.40	$ 49.88	$ 76.28	-
Hydro	1,985	3,181	18.3%	3.2%		$ 27.32	$ 1.48			$ 28.80	-
Biomass	-	-	0.0%	0.0%		$ -	$ 5.06		$ -	$ 5.06	0.00
Rooftop Solar	1,500	2,288	17.4%	2.3%	$ 1,373	$ 11.14	$ -	$ -	$ 49.50	$ 60.65	-
Utility Solar	3,631	5,820	18.3%	5.8%	$ 754	$ 8.74	$ -	$ -	$ 30.58	$ 39.31	-
Land-based Wind	-	-	0.0%	0.0%	$ 1,188	$ -	$ -	$ -	$ -	$ -	-
Offshore Wind	0	0	0.0%	0.0%	$ 4,800	$ 23.07	$ -	$ -	$ 98.77	$ 121.84	-
Total	16,524	87,447	60.4%	87.0%		$ 15.80	$ 0.97	$ 3.16	$ 32.81	$ 52.73	

Dispatchable	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Battery Discharge	0	0	0.0%	0.0%	$ 1,140	$ -	$ -	$ -	$ -	$ -	-
Flex Nuclear	9,000	13,102	16.6%	13.0%	$ 5,480	$ 93.42	$ 1.20	$ 2.60	$ 263.50	$ 360.72	-
Existing Gas CC	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$35.00	$0.00	$35.00	0.00
New Gas CC	0	0	0.0%	0.0%	$ 1,485	$0.00	$0.00	$31.00	$0.00	$31.00	0.00
Hydrogen Turbine	0	0	0.0%	0.0%	$ 1,257	$0.00	$0.00	$33.00	$0.00	$33.00	0.00
Coal	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$0.00	$0.00	$0.00	0.00
Steam Plants	0	0	0.0%	0.0%		$0.00	$0.00	$35.00	$0.00	$35.00	0.00
Existing Gas CT	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$54.00	$0.00	$54.00	0.00
New Gas CT	0	0	0.0%	0.0%	$ 979	$0.00	$0.00	$49.00	$0.00	$49.00	0.00
Total	9,000	13,102	16.6%	13.0%		$ 93.42	$ 1.20	$ 2.60	$ 263.50	$ 360.72	0.00

Total In-State Generation	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load		Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)
Total	25,524	100,549	45.0%	100.0%		$ 25.91	$ 1.00	$ 3.09	$ 62.87	$ 92.87

Regional Purchases		Generation (GWh/yr)		% Total Load
Imports		-		0.0%

	GWh/yr	% Total Load	% of Grid Renewables
Curtailments	2,851	2.8%	25.3%
Net Battery Load	0	0.0%	

Total Load (GWh/yr)	100,549

* Battery charging included in solar and wind generation.

Table B-5

All Gas & New Renewables → Baseload Nuclear plus Hydrogen-powered Turbines

Generation and Cost Summary — All Gas & New Renewables —> Baseload Nuclear & H2 Turbines — NREL Projected Cost — Year 2043

*Non-dispatchable**	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Existing Nuclear	2,978	25,061	96.1%	24.9%	$ 141	$ 3.70	$ 1.22	$ 4.09	$ 1.16	$ 10.17	-
New Nuclear	6,430	51,097	90.7%	50.8%	$ 5,663	$ 22.02	$ 0.97	$ 3.40	$ 49.88	$ 76.28	-
Hydro	1,985	3,181	18.3%	3.2%		$ 27.32	$ 1.48			$ 28.80	-
Biomass	-	-	0.0%	0.0%		$ -	$ 5.06	-	$ -	$ 5.06	0.00
Rooftop Solar	1,500	2,288	17.4%	2.3%	$ 1,373	$ 11.14	$ -	$ -	$ 49.50	$ 60.65	-
Utility Solar	3,681	5,877	18.2%	5.8%	$ 754	$ 8.77	$ -	$ -	$ 30.70	$ 39.47	-
Land-based Wind	-	-	0.0%	0.0%	$ 1,188	$ -	$ -	$ -	$ -	$ -	-
Offshore Wind	0	0	0.0%	0.0%	$ 4,800	$ 23.09	$ -	$ -	$ 98.83	$ 121.92	-
Total	16,574	87,504	60.3%	87.0%		$ 15.79	$ 0.97	$ 3.16	$ 32.82	$ 52.74	

Dispatchable	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load	Capital Cost ($/kw)	Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)	Annual CO2 Emissions (Mtons/yr)
Battery Discharge	0	0	0.0%	0.0%	$ 1,140	$ -	$ -	$ -	$ -	$ -	-
Flex Nuclear	0	0	0.0%	0.0%	$ 5,480	$ -	$ -	$ 2.60	$ -	$ 2.60	-
Existing Gas CC	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$35.00	$0.00	$35.00	0.00
New Gas CC	0	0	0.0%	0.0%	$ 1,485	$0.00	$0.00	$31.00	$0.00	$31.00	0.00
Hydrogen Turbine	9,000	13,107	16.6%	13.0%	$ 1,257	$13.73	$2.00	$33.00	$60.42	$109.15	0.00
Coal	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$0.00	$0.00	$0.00	0.00
Steam Plants	0	0	0.0%	0.0%		$0.00	$0.00	$35.00	$0.00	$35.00	0.00
Existing Gas CT	0	0	0.0%	0.0%	$ -	$0.00	$0.00	$54.00	$0.00	$54.00	0.00
New Gas CT	0	0	0.0%	0.0%	$ 979	$0.00	$0.00	$49.00	$0.00	$49.00	0.00
Total	9,000	13,107	16.6%	13.0%		$ 13.73	$ 2.00	$ 33.00	$ 60.42	$ 109.15	0.00

Total In-State Generation	Capacity (MW)	Generation (GWh/yr)	Capacity Factor (%)	% Total Load		Fixed O&M ($/MWh)	Var O&M ($/MWh)	Fuel Cost ($/MWh)	Capital Recovery ($/MWh)	In-State Generation Cost ($/MWh)
Total	25,574	100,611	44.9%	100.0%		$ 15.52	$ 1.10	$ 7.04	$ 36.41	$ 60.09

Regional Purchases		Generation (GWh/yr)		% Total Load
Imports		-		0.0%

	GWh/yr	% Total Load	% of Grid Renewables
Curtailments	2,901	2.9%	25.6%
Net Battery Load	0	0.0%	

Total Load (GWh/yr)	100,611

* Battery charging included in solar and wind generation.