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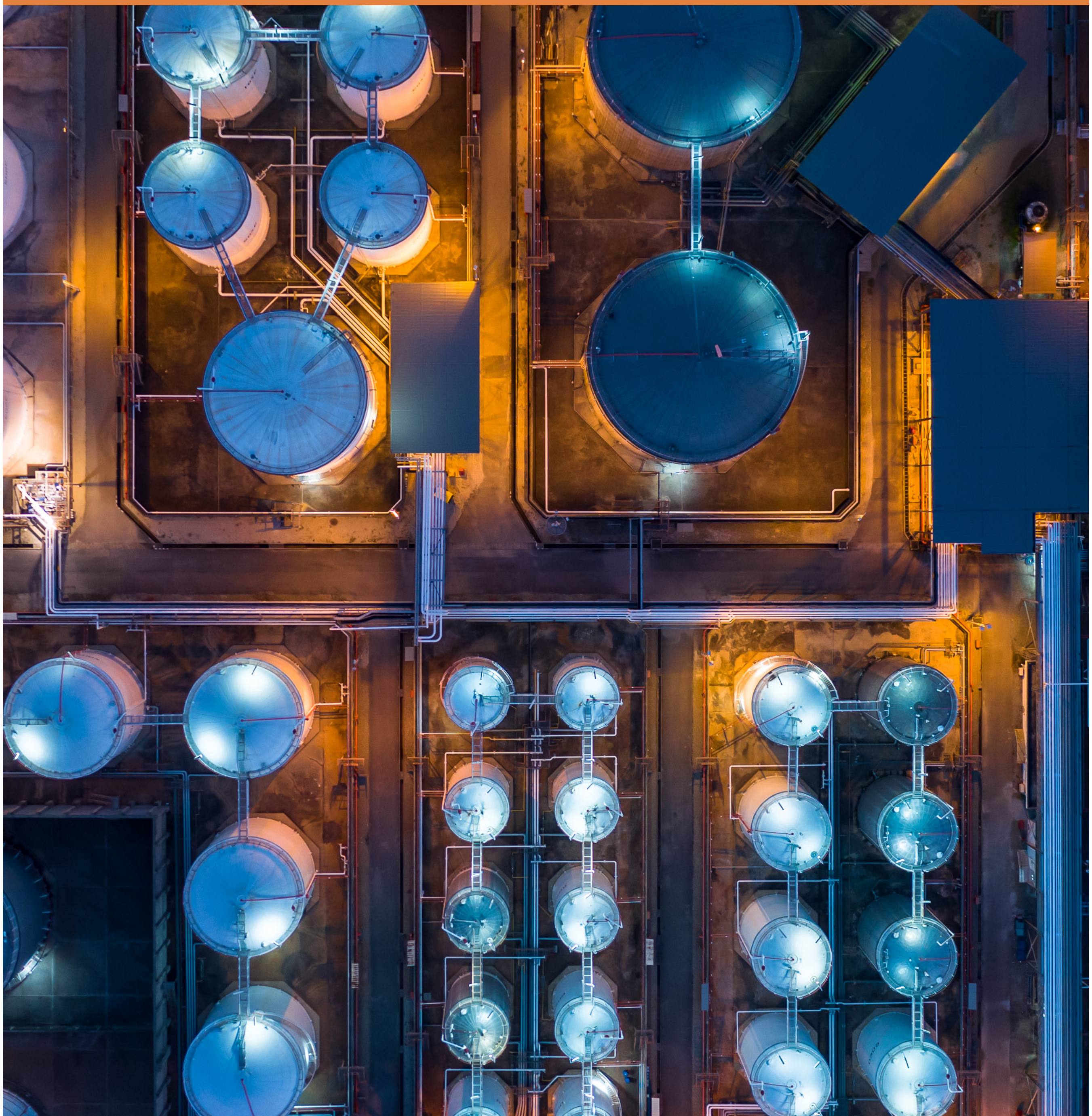
SUPERCHARGING ENERGY STORAGE INNOVATIONS IN NORTH CAROLINA



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https://doi.org/10.17615/vwxx-1r45

01. GOAL OF THE REPORT

The goal of this report is to analyze North Carolina's energy storage needs and capacity for innovation through research and development in academia and industry, and make recommendations for practitioners and policymakers that could supercharge advances in energy storage science and technology. These recommendations aim to provide opportunities for growth of the research enterprise for fueling American innovation, gaining energy independence, and training the modern energy workforce to meet a growing job market in North Carolina.

The report begins with an economic landscape analysis, providing insight into the current state of energy storage capacity in North Carolina and considers several economic scenarios that impact growth trajectories for renewable energy adoption and energy storage demand. Technology advances are likely needed to meet the expected demands for energy storage. Accordingly, the second part of the report analyzes the current state of energy storage research and development in North Carolina, with a focus on academic institutions but also highlighting key players in the private sector and government. Considering the demand and the status of research, several opportunities for investment or improvement become clear. From these opportunities, recommendations for stakeholders conclude the report.

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02. FOREWORD

North Carolina faces growing energy demands as a result of continued population growth and the emergence of new data centers and their accompanying electricity requirements. While the state's energy needs are increasing, at the same time a legislatively mandated carbon plan directs Duke Energy to achieve net-zero emissions by 2050. The evolving energy landscape presents both an opportunity and a challenge: to support economic growth through job creation and new technologies, while ensuring a reliable and affordable energy supply for residents.

In 2023, the North Carolina General Assembly invested $15 million in the North Carolina Collaboratory for the Next Generation Energy program. This investment supports university-led research aimed at advancing the energy sector in the state. These funds are fostering industry partnerships and driving innovation to help shape North Carolina's energy future.

The "NC Energy Storage Report" was funded through this Next Generation Energy program and highlights the critical role energy storage will play as a part of North Carolina's evolving energy portfolio in coming years.

The report showcases a collaborative academic effort to generate actionable data and modeling that can inform decision-making by industry leaders and state policymakers. To build on this momentum, the report calls for continued investment in research and greater support for private sector efforts – key steps toward a more reliable grid and energy infrastructure.

We expect that the information outlined in the report will serve as a guide and assist North Carolina in meeting its growing energy demands.

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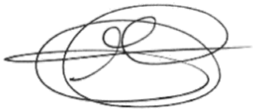


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03. EXECUTIVE SUMMARY

North Carolina's energy portfolio is changing. Natural gas is now the dominant fuel for electricity generation, with coal utilization sharply declining since 2007. Adoption of renewable energy sources such as solar and wind energy have also been increasing rapidly, accounting for 15 percent of electricity generation in 2023. The electrical grid is likely to face increasing pressure in the coming years as electric vehicles (EVs) and data centers consume more electricity.

In a scenario where solar and wind energy become major players in North Carolina's energy mix, there will be high demand for energy storage technologies. Solar and wind energy are intermittent sources, meaning their energy output is not constant. Although energy storage installations help manage peaks in electricity demand for all energy sources, including fossil fuels like natural gas, storing excess energy to be used at another time is critically important for intermittent renewable energy sources.

This report explores future energy scenarios in North Carolina and examines how energy storage costs influence renewable energy implementation. The high-level evaluation makes clear the need for improved energy storage technology. In the section that follows, we present an analysis of current research and development capabilities in North Carolina. An array of opportunities comes out of this two-part analysis, leading to recommendations for scientists, policymakers, and companies.

Section 5 considers what the grid of the future will look like in the Carolinas. Steep declines in the cost of wind and solar have led to a surge in installations. Future declines in the cost of short- and long-duration energy storage could spur renewables towards a large share of energy production on the grid. What gets built will reflect the relative costs and benefits of the technologies involved. We seek to understand how much storage will end up on the grid for a given set of costs and benefits.

Our model evaluates how different scenarios – such as declines in the cost of renewables and storage, or the introduction of a carbon tax – could affect investment in energy storage. We simulate both short-duration storage (used to shift energy within a single day) and long-duration storage (used to move energy across days), finding that each plays a complementary role in supporting grid reliability.

IN A SCENARIO WHERE SOLAR AND WIND ENERGY BECOME MAJOR PLAYERS IN NORTH CAROLINA'S ENERGY MIX, THERE WILL BE HIGH DEMAND FOR ENERGY STORAGE TECHNOLOGIES.

In every scenario we examine, investment in storage grows significantly once capital costs fall below certain thresholds, further affected by the cost of renewable energy and the details of energy policy. Our results indicate that storage is not only useful for supporting intermittent renewables like wind and solar but also helps conventional natural gas plants operate more efficiently by shifting energy to times of higher demand.

We find that energy storage has not yet hit the critical threshold at which point it will gain wide usage. Research and development (R&D) will be needed to decrease storage capital costs in the future and make further electrification of the grid possible. Once this happens, we find that developers will build significantly more storage for renewable energy.

For North Carolina, these findings suggest that sustained investment in energy storage research and cost reduction will yield major long-term benefits for grid reliability and clean energy adoption.

Section 6 summarizes current energy storage research and development in North Carolina, drawing on data from both academic and non-academic settings. The section focuses on batteries, fuels, and supercapacitors as energy storage technologies that could see performance improvements and cost reductions through research and development activities.

Academic investigators were identified with a systematic search, and the publications and grants associated with these investigators were sorted based on energy storage research themes. Companies with active R&D efforts in the same spaces were identified using keyword databases and grant activities.

Analyzing the historical data on where various types of energy storage research in North Carolina is ongoing reveals opportunities for basic scientists and engineers to collaborate more, for academics and companies to partner, and for strategic investments to accelerate technology development. These opportunities lead to five recommendations designed to supercharge energy storage technology in North Carolina.

RECOMMENDATIONS

1 Make better energy data available for NC

While public data sources have useful aggregate information on storage in the Carolinas, detailed information is neither available nor recorded anywhere. On a day-to-day level, it is unclear whether storage is charging or discharging. Grid operators in other regions, such as Texas, have made this information readily available. Making good policy decisions – whether they result from implementing a carbon tax, incentivizing construction of certain technologies, or something else – will rely on knowing how storage is being used in the state.

2 Enhance investments in long-duration storage

Both long- and short-duration storage would benefit from more research and development efforts. The country is building significant new solar and wind facilities. Storage technology is being implemented even with current capital costs, but most of the storage that has been built is short-duration storage. Our model shows that long-duration storage would be very useful for firms if its costs came down.

3 Establish mechanisms for basic science researchers to communicate and collaborate with applied scientists

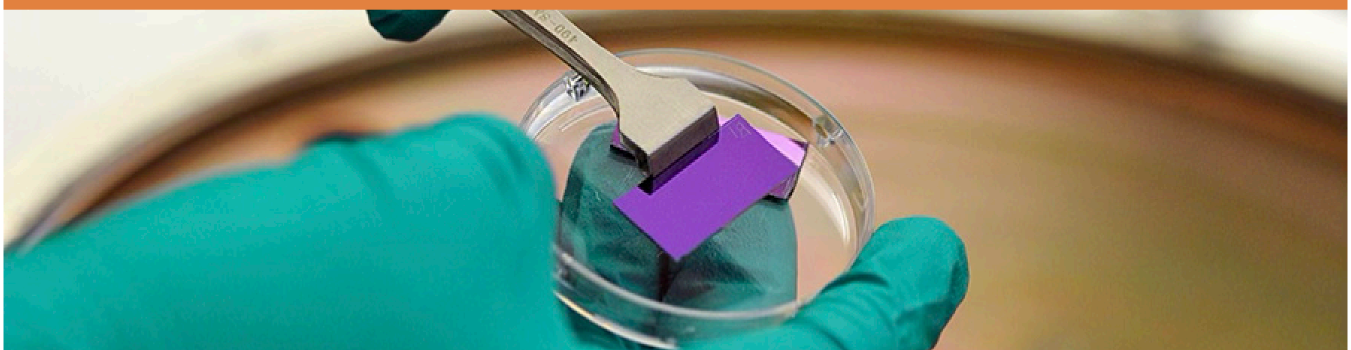
Chemists, physicists, biologists, and researchers from other fields that are active in basic research can benefit tremendously from collaborations with engineers and other applied scientists. Workshops and conferences that bridge fundamental and applied science can help strengthen the network. Seed funding proposals that require collaboration can also spark movement in this direction. The outcome of these efforts would be more publications and faster translation of basic science findings to technologies.

4 Invest in shared user facilities for energy storage research

Core laboratory user facilities in universities can serve as nucleation points for research. If a researcher has an idea that can impact energy storage technology, they are more likely to pursue that idea if there is a low barrier to entry. Having nearby shared user facilities helps ensure that a researcher does not need to make large financial investments in instrumentation and large time investments in training to try new ideas. This recommendation can also help more established researchers by providing instrumentation access and expert assistance to accelerate research. Shared user facilities are also generally open to the public and can help startup companies get off the ground and remain nimble.

5 Invest in metal-ion battery workforce development and innovations, including industry-academic partnerships

The presence of lithium resources and the trend in battery companies investing in North Carolina suggest that institutions of higher education have a great opportunity to train the future leaders of these companies. New programs that provide cutting-edge training to meet the future energy workforce needs would be valuable. Partnerships between academic programs and local businesses can help shape these programs. Incubator spaces in universities can help convert promising laboratory scale findings into startup companies or licensed technologies.



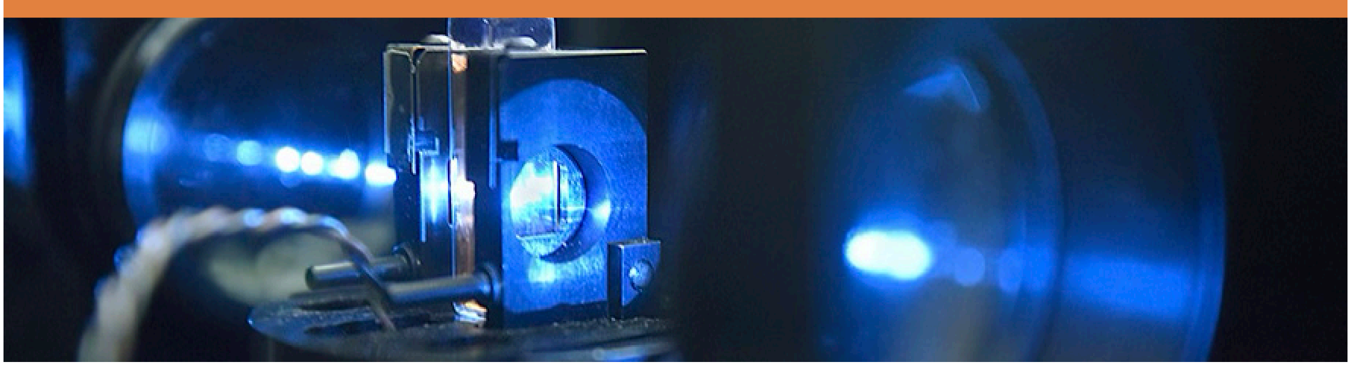


Photo credits: Donn Young, Jonny Andrews

04. BACKGROUND AND MOTIVATION

ENERGY STORAGE AND WHY IT MATTERS

It takes a lot of energy to power the people and companies of the state of North Carolina. North Carolinians consumed about 240 million BTUs (British thermal units), equivalent to about 50 barrels of oil per person each year, which is four times more energy than the state produces. Most of that energy is used by North Carolinians through the electrical grid (residential, commercial, and industrial) and the transportation sector. The statistics in this section come from the U.S. Energy Information Administration, which provides data up to 2023.[1]

North Carolina's electricity is generated from a mix of fossil fuel power plants (mostly natural gas), nuclear power plants, and renewables. The growth of renewables in the past decade is striking, rising to its current share of about 15% of the electrical grid's energy portfolio. Hydroelectric generation has remained steady in that time, while other renewables have more than tripled. Solar energy has been leading the way, with about four-fold increases in capacity over the past ten years to now account for about 10% of the total electrical power generation in the state. North Carolina now ranks fourth in the nation in solar generation capacity.

In the transportation sector, EV adoption has increased dramatically in recent years, from less than 10,000 registrations in 2018 to over 80,000 registrations in 2025.[2] Most vehicles in North Carolina use gasoline or diesel fuel for operation, but the shift towards electric vehicles is drawing more power from the electrical grid through home chargers and charging stations. New investments in data centers are also likely to drive increased demand for energy. And in 2025, technology companies made several significant investments in North Carolina for facilities dedicated to scaling their artificial intelligence (AI) models. The centers consume significant amounts of energy; recently, energy prices have increased by up to 20 percent in the Mid-Atlantic, with data centers cited as one of the main drivers of that increase. More details on renewable energy in North Carolina are included in Section 5.

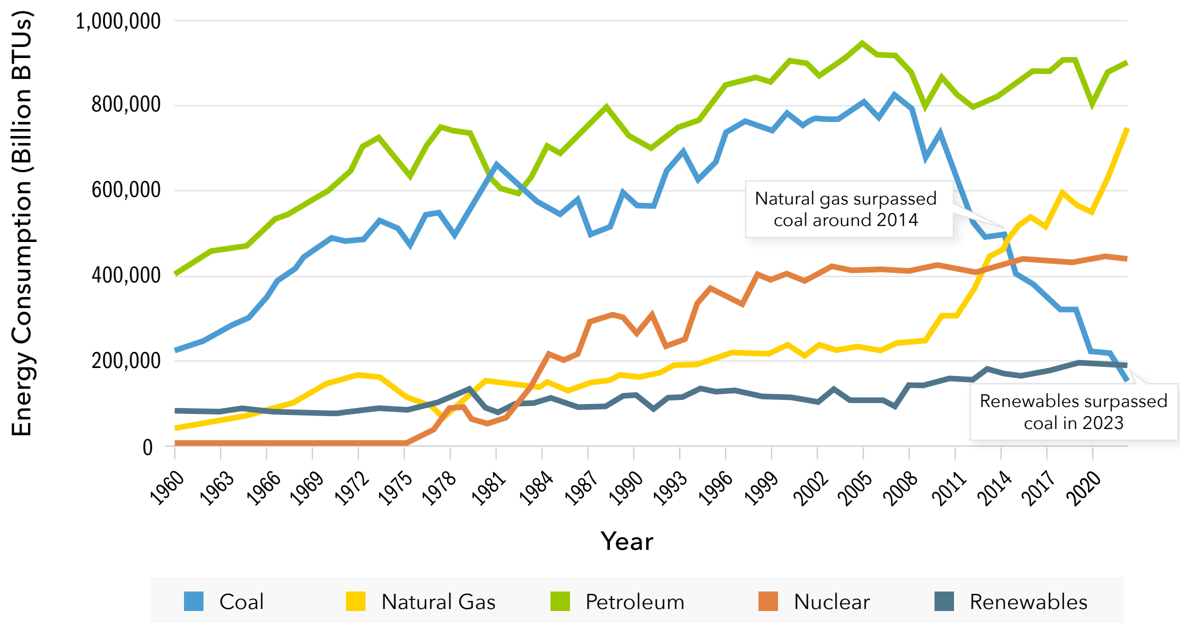
As renewables gain a larger share of the North Carolina energy portfolio, the state will need more energy storage capacity. Energy storage is the conversion of one form of energy into another that can be stored for some time before being utilized. It is necessary to utilize energy storage technologies in conjunction with renewable energy sources because electricity generation by renewables such as wind and sunlight is inherently intermittent: some days are windier than others, and the sun does not always shine. Renewable energy sources therefore are not always able to meet grid demand in real time. Even on a sunny day, solar power generation is greatest in the middle of the day, whereas electrical demand is highest in the evenings and mornings when lights and appliances are on and devices or vehicles are charging.

PROPER ENERGY STORAGE SOLUTIONS OVERCOME THE MISMATCH IN TIMING OF RENEWABLE POWER GENERATION AND END-USER ENERGY CONSUMPTION.

1 https://www.eia.gov/state/print.php?sid=NC#tabs-1

2 https://www.ncdot.gov/initiatives-policies/environmental/climate-change/Pages/zev-registration-data.aspx

Figure 1: North Carolina Energy Consumption By Source Across All Sectors, 1960 – 2022



The graph shows how coal, natural gas, petroleum, nuclear, and renewable energy consumption has changed from 1960 to 2022 in North Carolina. A striking decrease in coal and increase in natural gas is noted after 2008, with a steady increase in renewables as well.

Source: https://www.eia.gov/state/seds/seds-data-complete.php?sid=NC

Proper energy storage solutions overcome the mismatch in timing of renewable power generation and end-user energy consumption. For example, a battery can be charged using a solar panel during a sunny day by using the sunlight-generated electricity to perform a chemical reaction within the battery. That night, when the sun has set, the battery can power a device by producing a current as it discharges by reversing that chemical reaction.

When energy storage technology cannot keep up with energy production, that renewable electricity is wasted. Mismatches in energy storage, renewable electricity generation, and grid utilization can also lead to failures such as the country-wide blackout experienced in Spain (a country with about 50% renewable energy in its electrical grid)[3], in the spring of 2025.[4]

We consider two types of energy storage in this report: long- and short-duration. Short-duration storage is used for intraday transfers of energy, which is usually done using lithium-ion batteries. Short-duration storage is particularly useful for renewable generators. Sometimes, when solar power is plentiful, solar and wind generators face zero or even negative prices in energy markets. Short-duration storage co-located with those solar facilities allows generators to save energy produced during periods of low prices. Similarly, standalone short-duration storage can buy energy produced when prices are low and sell it when prices are high. Long-duration storage is used for storing energy over weeks, months, or seasons. It is often done using flow batteries, pumped hydro, or flywheels.

3 https://www.iea.org/countries/spain

4 https://cen.acs.org/energy/Editorial-Avoid-blackouts-building-batteries/103/web/2025/05

SPOTLIGHT

NC ENERGY POLICY SUMMARY

North Carolina passed the Renewable Energy and Energy Efficiency Portfolio Standard (REPS) in 2007, which called for 12.5% of the state's power to be generated by renewables. North Carolina was the first state in the Southeast to do so, and it expanded this policy to include all forms of clean energy in 2023, titled the Clean Energy and Efficiency Portfolio Standard (CEPS). In 2021, a clean energy law, House Bill 951: S.L. 2021-65, was passed with strong bipartisan support. It required that the state take all reasonable steps to reduce emissions by 70% of the 2005 level by 2030 and achieve carbon neutrality by 2050. Notably, this goal is similar to many other states nationwide; however, it does not require 100% renewable energy generation. This bipartisan bill focuses on net-zero emissions while allowing room for long-term coal and natural gas energy production. The CEPS is controversial. For example, Duke Energy has expressed concern about the aggressive interim target, citing that reaching such a measure would cost them an estimated $13 billion. They argue that this goal is no longer achievable due to a lack of infrastructure and would only burden customers who would be forced to bear the cost. Senate Bill 266, recently passed by the NC House and Senate overriding a veto by the Governor, abolishes the commitment to reduce emissions by 2030 (while maintaining the 2050 goal) and gives Duke Energy alternative financing mechanisms for building new power plants. Policy debate about clean energy continues currently, reflecting the uncertainty of the future renewable energy landscape, which can complicate investment decisions related to renewable energy generation and storage.

Sources:
https://apnews.com/article/north-carolina-power-plant-emissions-mandate-0930205bc28a2fd85163e5e850ae2c39;
https://dashboard.ncleg.gov/api/Services/BillSummary/2021/H951-SMRI-79(sl)-v-7;
https://www.ncuc.gov/Reps/reps.html;
https://www.newsobserver.com/news/state/north-carolina/article309882215.html

As the share of renewable electricity in North Carolina grows, the need for more capacity and improved technologies for energy storage will grow in tandem. In fact, without affordable technologies for energy storage, the implementation of renewables can even be hampered, as will be explored in detail in this report. The state of North Carolina has adopted several policies setting goals for energy in recent years. The SPOTLIGHT summarizes the policies most relevant to energy storage.

Looking at North Carolina's historical energy portfolio, natural resources, and policy goals, one can conclude that it is highly likely that energy storage technology will play a critical role in achieving the state's energy goals.

TYPES OF ENERGY STORAGE TECHNOLOGIES

There are many types of energy storage technologies. Four main energy storage categories can be defined: mechanical, battery, (super)capacitor, and fuels. Each category will be briefly described in this section.

Mechanical storage is the most mature technology for energy storage. A common technology pumps water uphill using renewable energy such as solar or wind and then opens a dam to provide hydroelectric power on demand. Another common technology involves flywheels that store energy upon rotating an axle, as seen in toy cars that can be rolled backwards to store energy, which then propels them forward when released. A final technology of note is molten salt, in which thermal energy heats a salt with ideal thermal properties, which later can be used to generate steam-powered electricity. Although the efficiency of some mechanical storage technologies can be high, the energy density is generally very low and the discharge rate (the speed with which electricity can be generated from the stored energy) is slow. This means that large facilities are needed to store energy, and they cannot rapidly respond to grid fluctuations. Because mechanical storage technologies are relatively mature and because of some of the limitations noted above, there is limited research and development effort, and the report will not discuss them further.

Battery storage is ubiquitous in everyday life. There are many different types of batteries, with the details of the underlying chemistry influencing the amount of power they can supply, their size and weight, and recharging characteristics. One notable aspect of battery storage technology is the vast span of utility. From millimeter sized batteries embedded in headphones to shipping-container-sized redox flow batteries, there's no "one size fits all" for battery storage, and wide-reaching research and development efforts are valuable. The leading rechargeable battery technology is currently lithium–ion batteries. EVs run on lithium–ion batteries, as do large-scale deployments to manage renewable electricity in the grid. Lithium–ion batteries can be up to 95% efficient, with energy densities 10–100 times higher than mechanical storage and rapid discharge times. North Carolina possesses large lithium deposits that have helped drive economic activity surrounding lithium–ion battery development in the state (see SPOTLIGHT).

Another battery technology of note is called redox flow batteries. These are much lower energy density than lithium–ion batteries, with deployments similar in size to shipping containers for grid storage capabilities. Flow batteries are better equipped for long-duration storage.

Supercapacitors have emerged as a player in energy storage due to extremely rapid discharge times. Although supercapacitors have lower storage capacity than batteries, recent increases in their capacity have raised the prospect of their role in energy storage technology development. Significant drawbacks of supercapacitors include relatively low energy density and poor long-term stability: supercapacitors undergo self-discharge, where a large fraction of the stored energy is lost on the timescale of weeks. The cost of supercapacitors is currently higher than batteries.

Fuels are molecules that hold large amounts of energy in chemical bonds. Breaking the bonds through combustion or using a fuel cell releases energy that can be used to power devices. Fuels are excellent for long-duration storage because they are chemically stable. Most fuels in the market today are not generated in an energy storage process but are fossil fuels extracted from the earth. To qualify for energy storage needs, *synthetic fuel* is required, made by a chemical reaction driven by renewable electricity. Water electrolysis to produce hydrogen and oxygen is the most mature technology. A new technology uses solar energy directly (rather than electricity from the grid) to generate what is known as a "solar" fuel. Directly utilizing solar energy to generate fuel could have efficiency advantages and is attractive for applications related to remote energy storage where there is no direct connection to the grid.

Each of the storage technologies described above is at a different level of maturity. Table 1 summarizes the energy storage technologies described here. Some are already deployed, others are at a nascent stage. And different technologies have different applications in energy storage. For example, synthetic liquid fuels (methanol, ethanol, gasoline replacements, etc.) are more likely to be valuable as drop-in replacements for the transportation sector while flow batteries are perfectly suited for grid-scale renewable electricity storage.

The goal of this report is to analyze the energy storage technology needs for the state of North Carolina and compare that with the capacity for innovation through research and development in academia and industry, culminating in recommendations for practitioners and policymakers that could supercharge advances in energy storage science.

The report begins with an economic landscape analysis that considers several economic scenarios that impact growth trajectories for renewable energy adoption and energy storage demand. The second part of the report analyzes the current state of energy storage research and development in North Carolina, with a focus on academic institutions but also highlights key players in the private sector or government. Considering the demand and the status of research, several opportunities for investment or improvement become clear. From these opportunities, recommendations for stakeholders conclude the report.

Table 1: Types of Technologies for Electricity Storage

	Max Power (MW)	Discharge Time	Max cycles (Lifetime)	Energy density (watt-hour per liter)	Efficiency
Flywheel	20	seconds – minutes	20,000 – 100,000	20 – 80	70 – 95%
Pumped hydro	3,000	4 hours –16 hours	30 – 60 years	0.2 – 2	70 – 85%
Molten salt (thermal)	150	hours	30 years	70 – 210	80 – 90%
Lithium-ion battery	100	1 minute – 8 hours	1,000 – 10,000	200 – 400	85 – 95%
Flow battery	100	hours	12,000 – 14,000	20 – 70	60 – 85%
Hydrogen	100	minutes – week	5 – 30 years	600 (at 200 bar)	25 – 45%

Source: https://www.eesi.org/papers/view/energy-storage-2019

SPOTLIGHT

NORTH CAROLINA LITHIUM RESOURCES

The mineral spodumene, $LiAl(SiO_3)_2$, is a very important ore source for lithium metal in the world. The Carolina Tin-Spodumene Belt in western North Carolina has large deposits of spodumene, one of which is in a large mine in Kings Mountain in southwest (Cleveland County) NC. The Cleveland County lithium mine operated from 1938 to 1988 and was the world's largest lithium supplier from 1950-1980. The mine was actually part of the Manhattan Project, providing the Lithium-6 for the first hydrogen bomb, but was closed in 1988 after the discovery of foreign deposits that were cheaper to extract. The lifespan of the lithium mine could be 10 more years. However, depending on the results of the feasibility study, the mine could be economically viable for up to 30 years, according to Albemarle. They've applied for permits in September 2024, and this whole process would involve dewatering the mine (it's currently filled with rainwater), relocating the wildlife (fish and turtles), and then starting the mining itself. Construction to reopen the mine could start in late 2025, depending on permit approvals, with production beginning in 2026. Piedmont Lithium is a $1B new mining investment in the same belt a little bit further north. The Gaston County, NC project is being designed as an integrated mining, spodumene concentrate and lithium hydroxide manufacturing operation. Carolina Lithium received their permits for construction and operation of their project from the state in April 2024.

Sources:
https://www.piedmontlithium.com/piedmont-lithium-receives-mining-permit-approval-for-carolina-lithium/;
https://www.charlotteobserver.com/news/business/article282106043.html

Charge – The process of storing energy in a battery.

Discharge – The process of using the energy stored in a battery to operate an electrical device.

Dispatchable Resource – Energy resources that can start up or wind down on a schedule. Natural gas plants are dispatchable, while solar and wind farms are not.

Efficiency – The ratio of useful energy output to total energy input. For the grid, this includes how well technologies convert resources like sunlight or wind into electricity and how much energy is retained through storage and generation processes.

Energy storage – The conversion of one form of energy (e.g. electricity, wind, solar) to another form (e.g. chemical, electrochemical) that can be used at a later time.

Inelastic – Describes a situation where energy demand does not significantly change in response to changes in price. Most residential consumers are unaware of real-time energy prices, meaning that demand for energy does not respond to real-time price changes.

Intermittency – A characteristic of renewable energy sources like solar and wind where energy production is not constant or controllable, due to variations in sunlight or wind conditions. This unpredictability drives the need for storage solutions.

Levelized costs of energy (LCOEs) – a per-MW measure of how much it costs to build a technology.

Lithium-ion battery – A rechargeable short-duration battery based on chemical reactions of lithium and usually cobalt oxide.

Long run – An economic modeling concept referring to a future state where all investments have been made, capital costs have stabilized, and technologies are no longer improving. It represents an end state for understanding market outcomes and grid composition.

Power density – The amount of power (energy per unit time) produced per unit of volume.

Redox flow battery – A rechargeable long-duration battery that can hold the charged chemical materials in large storage tanks for long periods before being flowed back through the cathode and anode materials for electricity generation.

Renewable electricity – Electrical energy generated from a renewable source such as solar, wind, or hydroelectric.

Round-trip efficiency – The percentage of energy retained during charging and discharging cycles. It does not account for energy lost during storage decay. For example, lithium-ion batteries have a round-trip efficiency of about 90%.

Solar fuel – A fuel produced using solar energy, typically by converting sunlight into chemical energy (e.g., hydrogen via electrolysis).

Storage decay – The amount of energy lost simply by storing it over time, even without usage. It's particularly relevant for comparing short-duration storage (which may have higher decay) with long-duration storage (which often has negligible decay).

Supercapacitor – Also called an ultracapacitor; materials with very high capacitance compared to traditional capacitors that offer storage capabilities in between capacitors and batteries, with fast charge/discharge rates.

Synthetic fuel – Useable fuels (molecules that can be combusted) that are synthesized from smaller building blocks, as opposed to fossil fuels which are generated via the breakdown of complex organic material.

Photo credits: Megan Mendenhall, Donn Young, Syzygy Plasmonics

05. ECONOMIC LANDSCAPE ANALYSIS

America's energy grid is undergoing its second significant transformation since markets were restructured in the 1990s. In the 2000s, natural gas rapidly replaced coal as the dominant fuel for electricity generation, thanks to technological breakthroughs that lowered extraction costs. Today, a similar shift is underway with renewables. In 2024, nearly 90% of planned grid-scale generation investments involved renewable sources, and close to half those included energy storage components – a dramatic change from just 2017, when less than 10% of new capacity involved storage.[1]

This shift is being driven by economics. In 2025, industry experts estimated that, on a per MW basis, newly constructed combined cycle natural gas plants cost roughly twice as much to build as newly constructed solar and wind firms. The generators planning to build new solar and wind plants are building storage as part of their plants even though storage is still expensive.[2]

The price of renewables reflects years of falling costs. Figure 2 shows how wind and solar capacity factors, or how much of a resource can be converted into energy, have risen steadily over the past 15 years, reflecting substantial R&D spending in the industry.[3] Levelized costs of energy (LCOEs), a rough measure of how much it costs to build a technology, for solar and wind have fallen over the last decade, driven by technological innovation and scale.[4] Energy storage is a less mature market, though recent R&D efforts in areas like lithium-ion and flow batteries have begun to bring down costs and improve efficiency. If storage follows the same trajectory as renewables, it could become a central part of grid operations in the near future.[5]

Existing storage development has been concentrated in California and Texas, two states that have been national leaders in building renewable energy infrastructure. The most recent data on individual storage facilities covers facilities operating as of December 2023. Total battery power capacity in the U.S. was 17,000 megawatts (MW). California had more than 8,000 megawatts of energy storage installed and operating. Texas was in second place with just under 4,500 MW of storage. Operating MW fell off quickly thereafter: Arizona had 1,000 MW operating and remaining states had around 500 MW or less. North Carolina ranked 15th in total storage capacity, though it had just 58 MW in operation. North Carolina's lack of storage stands in stark contrast to its leadership on solar generation. As we discuss in our results section, storage will likely play an important role in North Carolina's future grid infrastructure.

Figure 3 shows the location of storage facilities across the U.S. as of December 2023. Most storage is co-located with energy generation facilities – typically solar photovoltaic farms, but also wind farms, hydro plants, and sometimes natural gas and coal plants. North Carolina had 17 storage facilities, 14 of which were co-located with solar farms, ahead of some states with ample renewable resources, like the Upper Midwest, which is a national leader in wind generation.

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1 Potter, "Inside the Interconnection Queue," 2025.

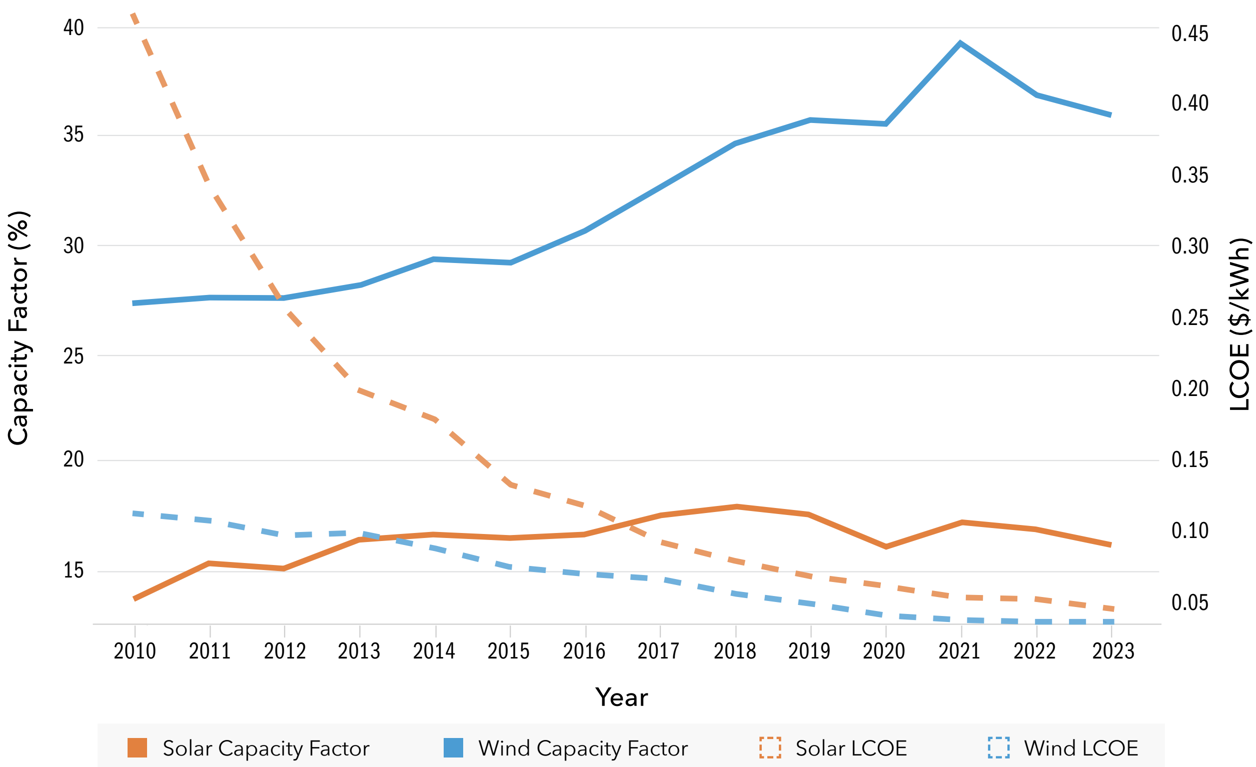
2 U.S. Energy Information Administration, "Levelized Costs of New Generation Resources," 2025.

3 Osborne, "R&D Spending Analysis of 21 PV Manufacturers," 2019; see also, IRENA, "Renewable Technology Innovation Indicators," 2022, NREL, "Champion Photovoltaic Module Efficiency Chart," 2025, and Nahm, "Exploiting the Implementation Gap," 2017.

4 LCOEs add up the (discounted) operating and capital expenditures for a generator and divide by the (discounted) expected energy output of that generator to arrive at a cost per MW that can be compared across generator types. LCOEs for renewables increased following the passage of the One Big Beautiful Bill Act in July 2025, which made tax credits much harder for renewable generators to obtain. Table 2 keeps production and capital costs separate for each technology, which is needed to account for entry and exit. The costs in Table 2 are from a 2021 report. Zeitlin, "Everyone's Favorite Energy Cost Metric Is Wrong, Environmental Group Says," and Pontecorvo, "Treasury Guidance for Wind and Solar Tax Credits Could Have Been So Much Worse."

5 Chandler, "The Reasons Behind Lithium-Ion Batteries' Rapid Cost Decline," 2021 and Orangi et al., "Trajectories for Lithium-Ion Battery Cost Production," 2023.

Figure 2: Solar and Wind Progress



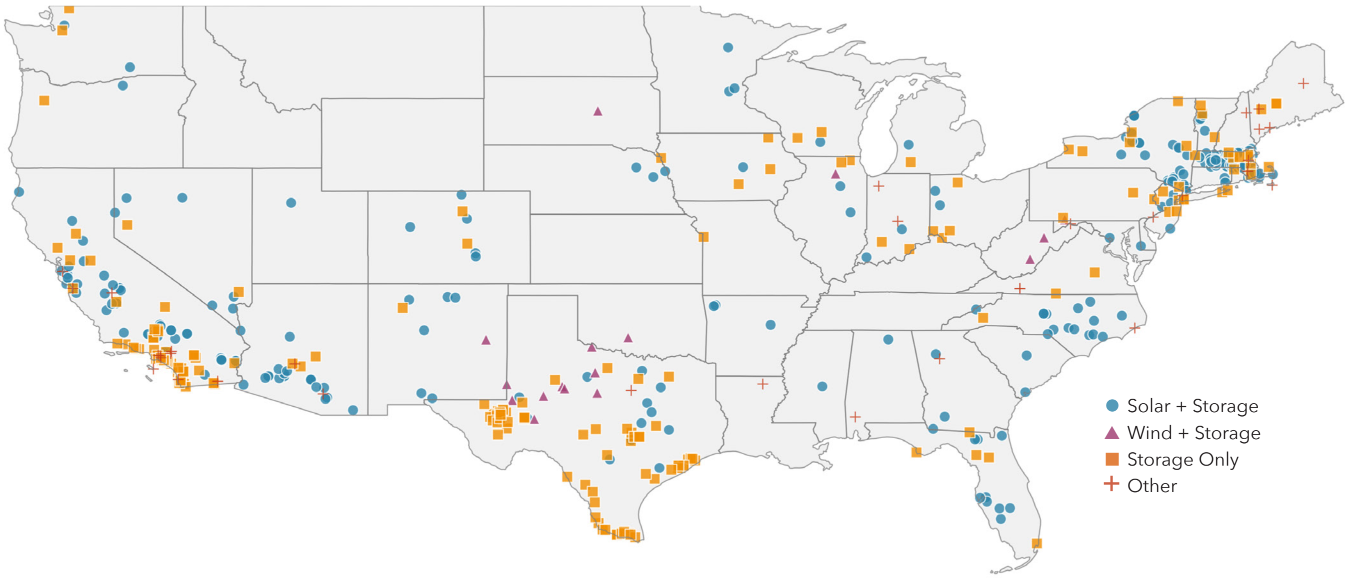
This graph shows growth in capacity factors and cost declines for wind turbines and solar panels from 2010 through 2023. The left axis shows capacity factors for each technology. Capacity factors represent the share of incoming energy that is converted to usable energy. The right axis shows the Levelized Cost of Energy (LCOE) for each technology. LCOEs represent the discounted cost of producing 1 KWh using a technology. Costs include the capital costs, operating costs, and fuel costs for a technology. Data from IRENA (2023).

The U.S. has more than doubled its storage capabilities since 2023. As of June 2025, total storage capacity in the U.S. stood at 35,000 MW.[6] Internationally, the U.S. is a leader in energy storage capacity, though its resources fall far behind China's. In January 2025, China reported more than 70,000 MW of installed storage in 2025 – a 130% increase over the previous year.

Energy demand is highly inelastic. Residential consumers do not typically know what the hourly cost of energy is when they are using it – they use as much as they need and pay the bill at the end of the month. Commercial and industrial consumers may adjust their energy use based on real-time prices, but most demand remains fixed. This creates issues for grid operators, who must source the amount of energy needed to meet demand but who do not want to oversupply energy to the grid.

6 It is unclear exactly how much of that additional storage is in North Carolina. Texas announced that in early 2025 it had more than 8,500MW of energy storage in operation, roughly doubling its energy storage capacity from December 2023. As of May 2025, California had 12,500MW of energy storage in operation.

Figure 3: Storage Facilities in Continental U.S.



This map shows the location of all operating storage facilities in the continental U.S., based on data from the Lawrence Berkeley National Laboratory, "Hybrid Power Plants". 17 of 544 total storage facilities are in North Carolina. 14 plants are solar photovoltaic farms co-located with storage facilities. A plant counts as Solar + Storage if it has any solar generation co located with storage facilities. A plant counts as Wind + Storage if it has any wind (and not any solar) co-located with storage facilities. Other includes fossil, biomass, and hydro plants co-located with storage.

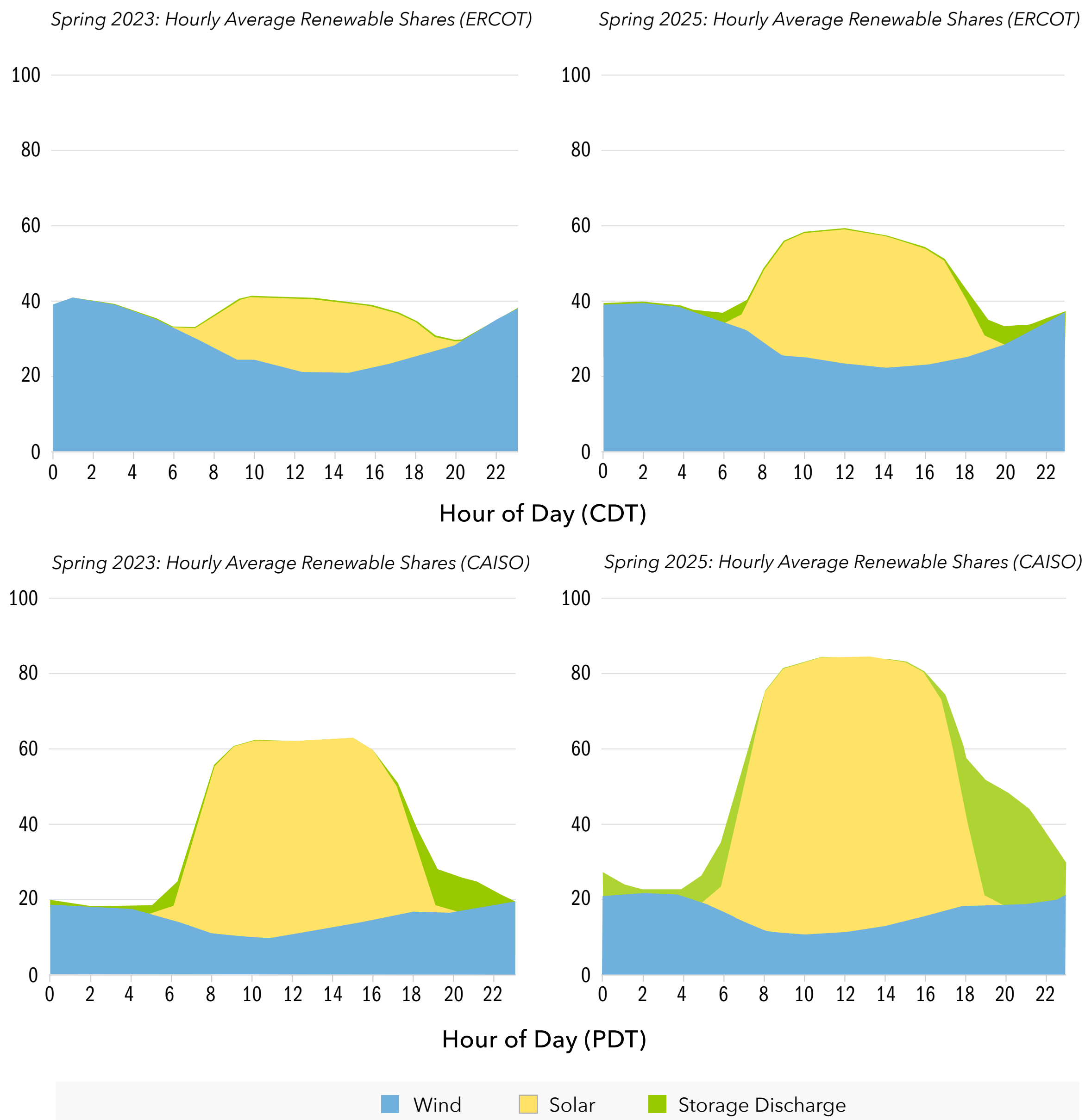
The bulk of energy in the U.S. today comes from dispatchable sources like natural gas plants. Dispatchable resources can be called upon to provide power when needed and consistent power flows to the grid. Historically, grid operators would forecast demand and pay for supply from an appropriate number of dispatchable power plants. Sometimes, demand for energy spikes and outpaces available supply. Absent storage, the grid would need to build extra plants to meet that demand, even if demand only peaks for a couple days every year. Some natural gas plants would then sit idle for most of the year. With energy storage, the grid can avoid constructing plants that sit idle and instead can use storage to push supply from low demand days toward days when demand peaks above what the grid could supply with dispatchable resources alone.

Energy storage is particularly useful for renewables on the grid. Renewables suffer from an intermittency problem – grid operators cannot control when solar panels generate power. Short-duration storage helps grid operators take excess energy from the daytime and shift it to supply energy at night. Long-duration storage takes some of the excess energy from particularly productive days – when wind and solar generation are high – and shifts it to periods spanning multiple days when weather conditions are poor, such as during extended cloudy periods or when high-pressure systems bring calm, low-wind conditions for several consecutive days.

Figure 4 shows how storage is used in Texas (top row) and California (bottom row). Each panel shows, for each hour of the day, the average share of total generation that renewables provide in each region. The left panels show data from spring 2023 and the right panels show data from spring 2025.

Both Texas and California have seen a wide expansion in the quantity of storage that is used on the grid even over a two-year period. In Texas, storage is used most heavily during evening periods after solar energy dies down and before wind energy ramps up. In 2023, storage met an average of 0.38% of all energy needs at 7 p.m. By 2025, it met an average

Figure 4: Hourly Average Renewable Share of Dispatched Electricity in the Spring



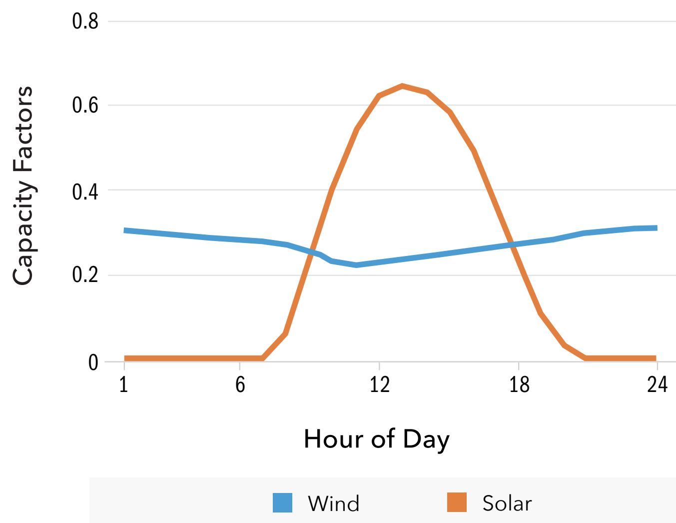
This graph shows, for each hour of the day, the average share of total generation that is provided by renewable resources (solar, wind, and storage) in Texas (ERCOT) and California (CAISO). Averages are taken over all days in March, April, and May for 2023 and 2025. Data are from GridStatus.io.

of 4.6% of all energy needs at 7 p.m. In California, storage provided an average of 30.5% of all energy at 7 p.m. in 2025. This illustrates how storage can complement renewables – as more solar works its way onto the grid, storage will become increasingly useful for meeting demand during the evening hours when the sun is low and wind is gentler.

Energy storage is poised to become more important as demand for energy grows. The North American Electric Reliability Corporation forecasts that demand for energy will grow by 21.5% over the next decade, with most of that growth coming from data centers.[7] Further demand for energy storage comes from electric vehicles, which rely on lithium batteries for power.

7 Norris et al., "Rethinking Load Growth," 2025.

Figure 5: Wind and Solar Capacity Factors in the Carolinas



This figure shows the share of facility capacity (capacity factors) that can be converted into energy for wind and solar generation plants in the Carolinas. For example, if a 10MW solar farm produces 8MW of energy in an hour, its capacity factor will be 0.8. Capacity factors measure the amount of sunlight or wind that can be harnessed. They can be affected by weather and technological efficiency, among other factors.

Energy storage will be important for North Carolina as it continues to build out its renewable energy infrastructure. As Figure 5 shows, North Carolina has the potential to harness ample solar energy during the daylight hours and consistent wind energy throughout the day.

Our goal in this section is to understand the role that energy storage will play in the grid of the future. We seek to answer three specific questions:

1. How much storage will the Carolinas need?
2. How does demand for storage differ across long- and short-duration storage types?
3. How does storage demand and supply vary under different policy environments and with different assumptions about technological progress and growth?

This report synthesizes recent academic literature that considers generation of electricity in the long run and the role of renewables and storage.[8]

Our model seeks to understand what the grid will look like in the long run. The long run is an abstract concept in economics meant to approximate what happens once storage capital costs stop declining, renewables stop improving, and firms make all the profitable investments that are feasible. Once investments have been made, firms produce energy. Long-run modeling is a useful way to analyze the economic forces that drive investment. One advantage of this approach is that it requires minimal data and analysis requirements. Rather than trying to predict the precise evolution of every source of generation in the electricity grid over time, a long run model describes an end state in which all investment has taken place.

8 Holland et al. (2024) and Marsh et al. (2025)

Investments are power plants. Firms construct new plants, accounting for the availability of sun and wind at an hourly level in the Carolinas, the load generation profile of the power (i.e., does it have ramping costs or intermittency problems?), and efficiency of the technology (i.e., how much sunlight does the panel turn into energy or how much of the energy is lost during storage?). Existing plants either retire or keep producing energy; what matters is whether they can produce energy more profitably than other potential power plants.

Energy production depends on plant operating costs, annual capital costs, and demand. Table 2 shows the operating and annual capital costs that we use in our model. To account for the impact of data centers, we assume demand will grow by 125 MWs every hour of the year. We model production for 8,760 individual hours, representing all the hours in a year. Each hour, each plant in the simulation decides whether to produce energy, which entails either selling the energy they produce or storing it while incurring operating costs. Renewables have no operating costs.

We use two types of energy storage in our model: short-duration and long-duration. For each hour of production, a firm can choose to divert energy to either short-duration storage, long-duration storage, or sell it in the electricity market. Storage is characterized by two properties. First, its round-trip efficiency, the amount of energy that is lost in the transferring process, including transfers into the storage unit and transfers out of the storage unit. The second property is storage decay, the amount of energy that is lost when energy is stored. Short-duration storage has high storage decay and high round-trip efficiencies – we use estimates for lithium-ion batteries, assuming a round-trip efficiency of 95% and storage decay of 2.5% per hour. Long-duration storage has low storage decay and lower round-trip efficiencies – we use estimates for redox flow batteries, assuming a round-trip efficiency of 70% and storage decay of 0. This reflects the usage pattern of short- and long-duration storage: short-duration storage is ideal for intraday use, while long-duration storage is often used to smooth energy production across days. Figure 6 shows how the efficiency of each storage type varies depending on how long the storage is used for. The break-even point comes at 12 hours, meaning it is best to use short-duration storage for periods of up to half a day.

We use demand and capacity factory data from 2019 and cost projections for the near-future to model the long-run. This means that our baseline results show what the grid would look like in the future if operating

SCENARIOS CONSIDERED IN ECONOMIC LANDSCAPING ANALYSIS

- **Baseline:** Operating costs, annual capital costs, and natural gas prices all fixed to values from 2019.
- **Renewables 25/50/75/95% Cheaper:** this scenario imagines what would happen if capital costs for renewables decline by 25%. (Operating costs for renewables are essentially zero.)
- **Storage 25/50/75/95% Cheaper:** this scenario imagines what would happen if short- and long-duration storage each got cheaper.
- **$100 Carbon Tax:** this scenario imagines that a carbon tax is imposed on natural gas plants – operating costs for each plant rise by $100/metric ton of natural gas they use. Rising natural gas prices would also increase operating costs for natural gas plants and could generate similar long-run behavior to what we find in our model with a carbon tax.
- We also model the long-run development of the grid under various combinations of the above policies and cost scenarios.

costs and capital costs reach their projected values and stay there in the long run. Further scenarios, like decreasing costs for renewables, simulate expected outcomes if annual capital costs for renewables decrease. We also assume that the price of natural gas is constant from 2019. These are important assumptions: natural gas prices, for example, are volatile and depend on production in foreign countries, among many other considerations. Our assumptions are meant to be as simple as possible.

While we model specific policies like a carbon tax and renewables innovation, our results have broader implications than those specific policies. A carbon tax is similar to modeling an increase in the price of natural gas, as a carbon tax only makes natural gas generation more expensive for firms. Renewables innovation makes capital costs for renewables cheaper – similar to what would happen if renewable capacity factors continued to rise. Where relevant, we make efforts to show how results are sensitive to these underlying assumptions. Note that we do not consider land acquisition costs for firms. Land costs vary across the Carolinas, which could push generations away from the precise mix we simulate in the long run.

RESULTS

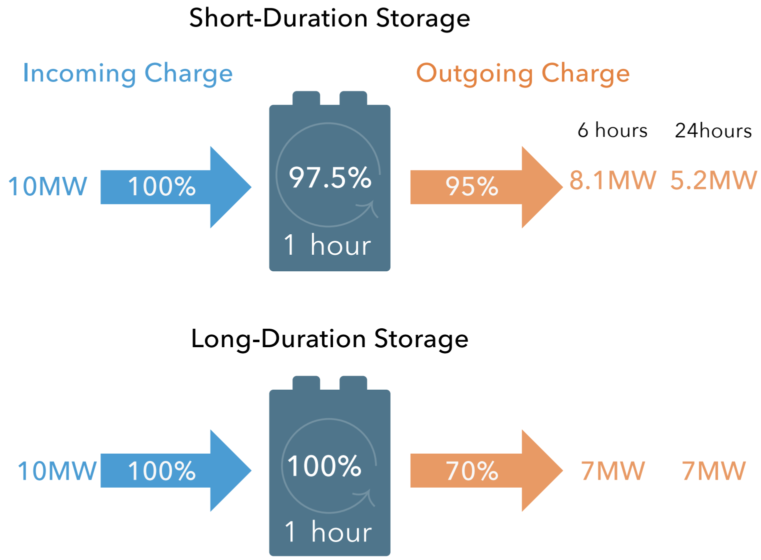
Figure 7 summarizes our main findings. Each figure depicts the demand for the respective storage duration (the x-axis) as the capital cost of the storage technology varies (the y-axis), i.e., these are the industry demand curves for short- and long-duration storage in long-run equilibrium. The color and line pattern of each demand curve comes from six future scenarios that may occur in the electricity market in the near future. These scenarios are combinations of changes to the capital cost of renewable electricity generation, i.e. wind and solar, as well as the introduction of a carbon tax per metric ton of carbon emissions. The orange line shows the baseline scenario that resembles the current state of the industry, i.e. the capital cost of renewable electricity generation from wind and solar remains the same and carbon emissions remain untaxed, which is what we would expect energy storage demand to look like if renewables got no cheaper and firms made entry and exit decisions. The green line shows the scenario where renewable costs decrease by 25%, and the blue line shows the scenario where renewable costs decrease by 50%. Dotted lines show scenarios where a carbon tax of $100 per metric ton is introduced.

Table 2: Operating and Capital Costs for Technologies in Model

	Operating Cost ($/MWh)	Annual Capital Cost ($/MW)
Solar PV	0	83,274
Wind (onshore)	0	132,602
Advanced Nuclear	2.38	528,307
Gas Combined Cycle	26.68	79,489
Gas Combustion Turbine	44.13	54,741
Short-Duration Storage	0	18,935 ($/MWh)
Long-Duration Storage	0	34,083 ($/MWh)

This table shows the baseline operating and annual capital costs used in the model. The costs come from the 2021 Annual Energy Outlook. $/MWh reflects the capital costs incurred for adding an additional hour of energy storage to the grid. Energy storage capital costs are based on capital costs for a 4-hour storage unit.

Figure 6: Illustration of Short-Duration and Long-Duration Storage Parameters

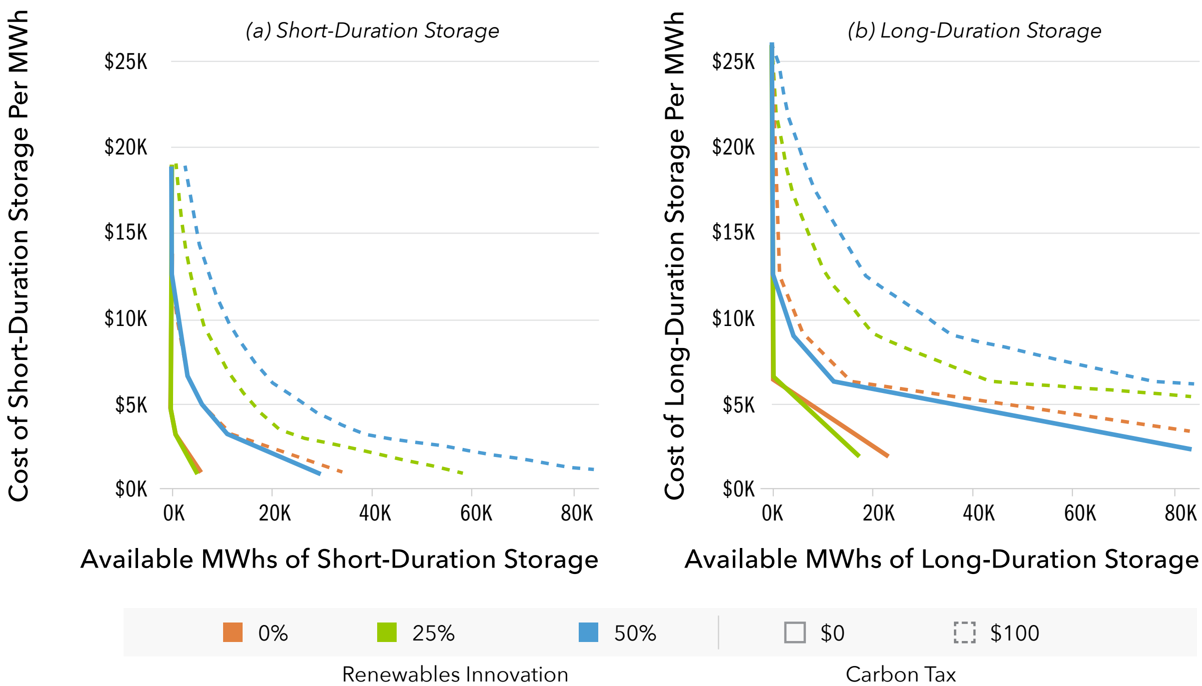


Short-duration storage parameters correspond to lithium-ion battery technology. Long-duration parameters correspond to redox flow, pumped hydro, and other related long-duration storage technologies.

We find that, at baseline, anywhere from 0 to roughly 50 MWh of short-duration energy storage and 0 to 25 MWh of long-duration energy storage are used on the grid. The volume of storage used depends on how costs shift, however. If solar and wind capital costs decrease by 25%, the quantity of storage demanded does not change by very much – solar and wind are only used sparingly in such a scenario, and so energy storage is only marginally useful. The carbon tax has a more meaningful effect on the demand for storage. If a carbon tax of $100 is implemented, the quantity of storage demand increases significantly, from roughly 50 MWh to 500 MWh for short-duration storage and 25 MWh to 250 MWh for long-duration storage.

Across all scenarios, demand for short-duration and long-duration storage is roughly the same when the cost of storage capacity is expensive. As the price of storage capacity decreases, long-duration storage becomes more attractive, leading to more long-duration capacity. However, it is important to note that in the current state of the industry, long-duration storage is roughly 1.8 times more expensive than short-duration storage. If this ratio remains the same in the future, demand for short-duration will be roughly twice as high as demand for long-duration storage. As short- and long-duration storage capital costs decrease, firms continue to use each technology in roughly equal proportions, indicating that they serve complementary roles. Short-duration storage helps smooth hourly supply fluctuations, while long-duration storage addresses multi-day gaps.

Figure 7: Storage Demand Under Various Scenarios

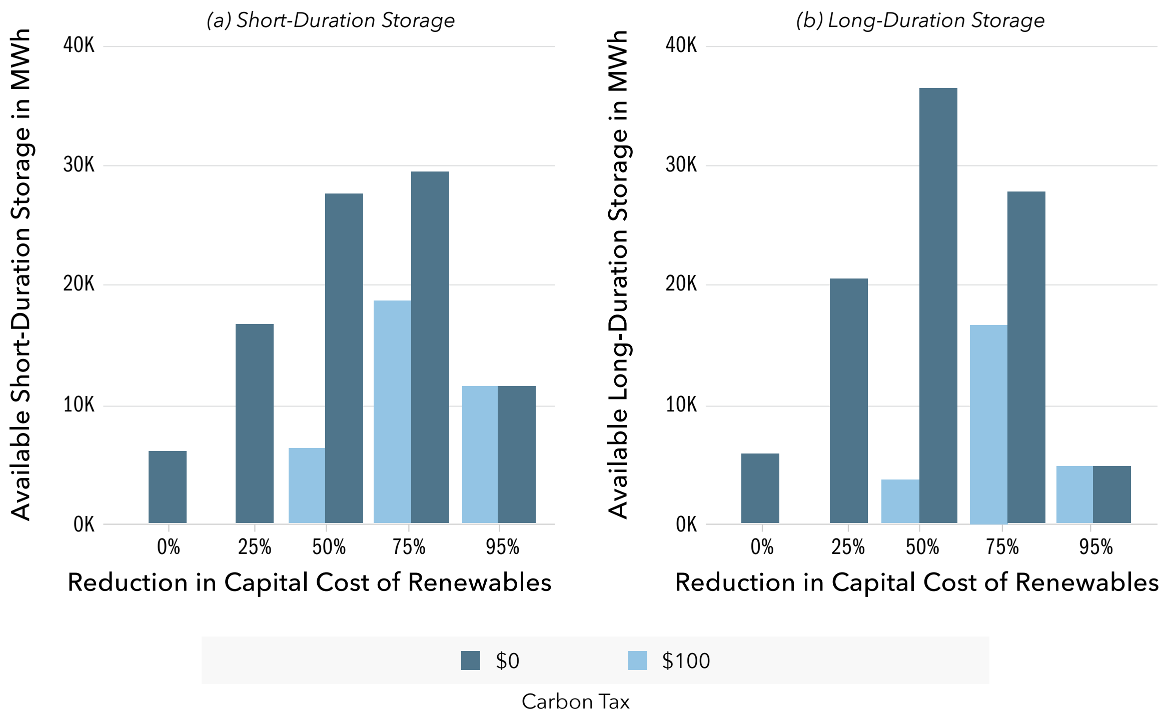


Results from simulation of long-run investment under various assumptions about decreases in capital costs for generating electricity from renewable sources and about adopting a carbon tax of $100 per metric ton. The capital costs of each type of storage are varied in each scenario to create the demand curves.

Introducing a carbon tax increases demand for storage significantly. A carbon tax raises the operating cost of natural gas, encouraging more renewable deployment. But renewables are intermittent – they need storage to serve as reliable baseload substitutes. Similarly, making renewables cheaper expands their share of generation, increasing the value of storage. In the combined scenario (dotted blueline), these effects reinforce one another, producing the largest increase in storage demand. Interestingly, we also find that energy storage is used even when renewables are not used. This is because natural gas plants can use storage to shift energy production to more valuable times of the day and year without paying operating costs.

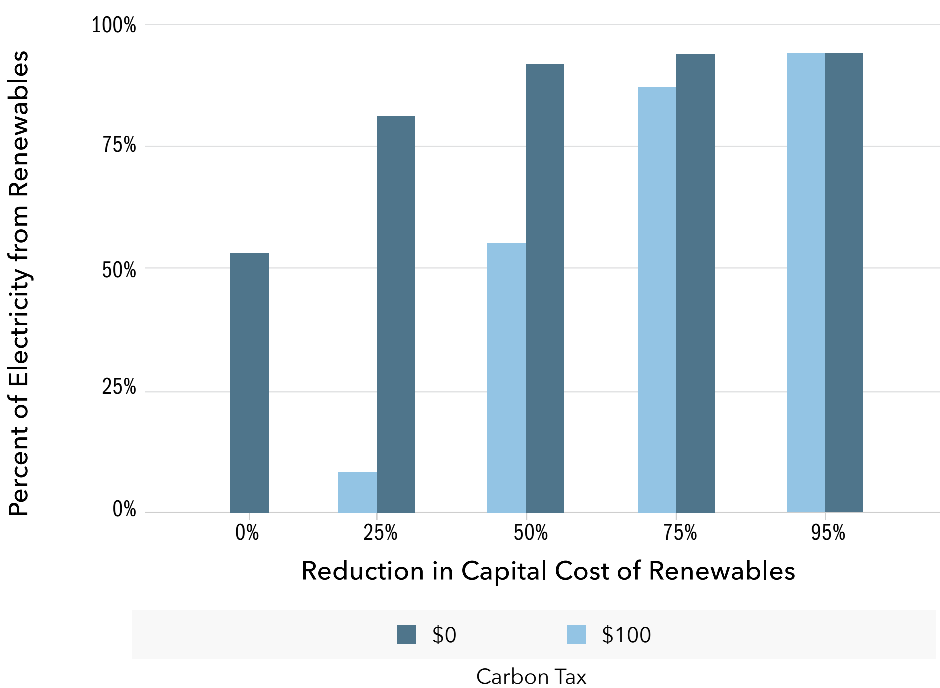
Without a carbon tax, demand for storage only begins to increase significantly after the capital costs of renewables decrease by at least 50%. Figure 8 shows the demand for each type of storage under the different scenarios, assuming a 25% reduction in the cost of capacity for each type. For both short-duration and long-duration storage, the demand for storage increases moderately when the cost of renewables decreases by 50% and significantly increases after a 75% reduction. However, notably, the demand for storage decreases when the cost of renewables decreases by as much as 95%. To understand why, Figure 9 shows the share of electricity generated from renewables in each scenario. As renewable generation becomes inexpensive, renewables are

Figure 8: Storage Demand by Renewable Cost Reduction



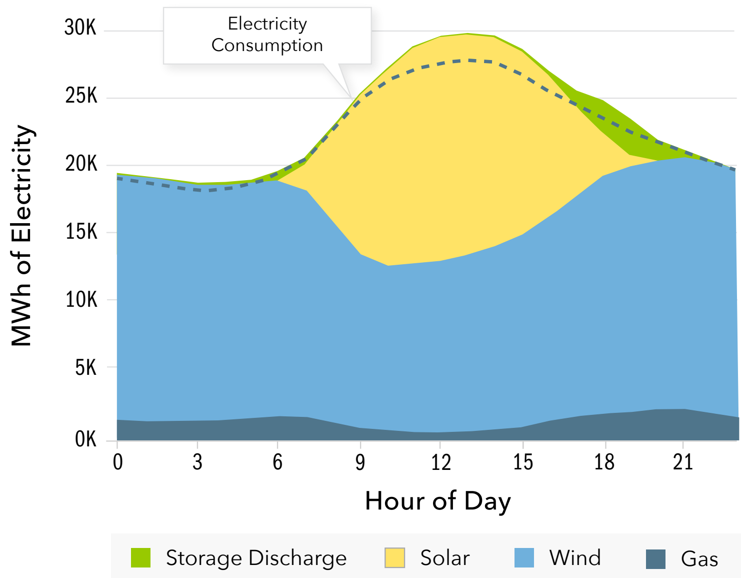
Each figure depicts how much storage is demanded for both long- and short-duration storage under each scenario for capital cost reductions.

Figure 9: Share of Electricity from Renewables by Scenarios



This figure depicts the share of total energy generation provided by renewables for various short- and long-duration storage capital costs reduction scenarios.

Figure 10: Projected Electricity Generation and Consumption Over Average Day



This figure shows the amount of electricity generated from each source for an average day of the year for the scenario where the capital costs of renewables, long-duration storage, and short-duration storage all decrease by 50% and a $100 carbon tax is imposed.

responsible for all generated electricity. Instead of investing in storage capacity, firms may find it more profitable to invest in generation capacity to produce enough electricity even when renewables are less effective, e.g. during the night or winter.

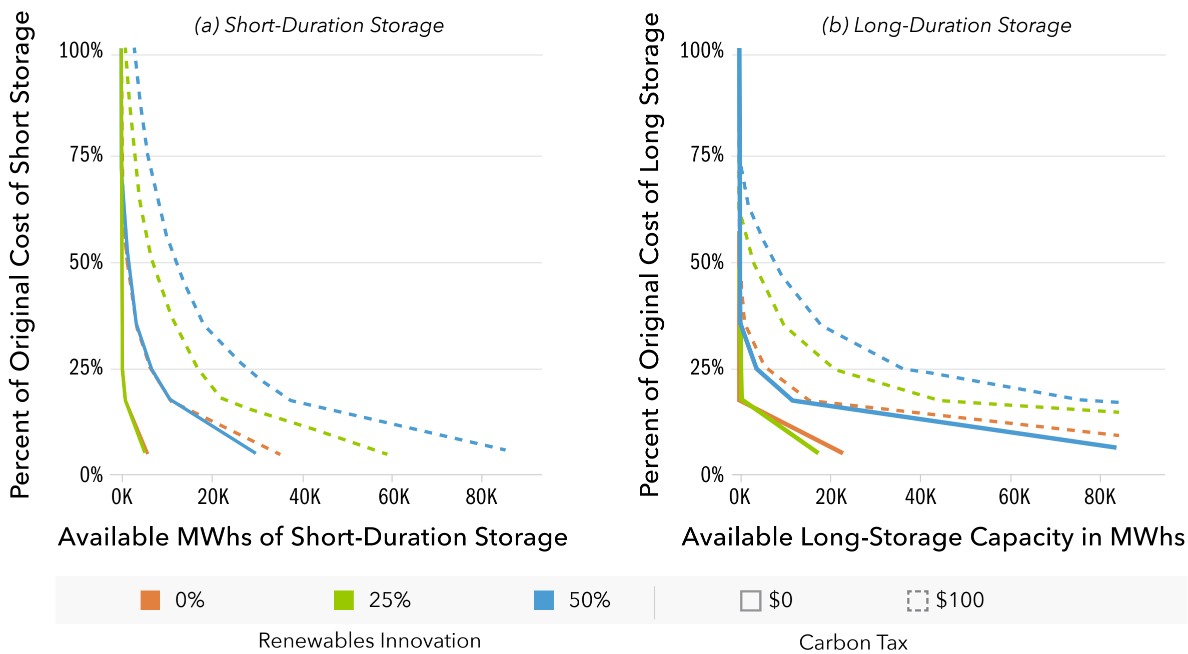
The decrease in storage demand for extremely high levels of renewable cost reduction is interesting but ultimately unlikely to occur. Renewables have already moved far down the cost curve – future cost reductions will be increasingly difficult to achieve. The cost reductions that have already come to pass, however, reflect the value of investing in R&D. Ten years ago, demand for utility-scale solar power remained low.[9] This was despite decades of intensive R&D and dramatic cost decreases. Today, so many developers are seeking to build solar farms that grid planners are overwhelmed with the volume of requests.[10] Once capital costs hit a critical threshold, demand skyrocketed.

Figure 10 shows the average day of electricity generation and consumption for a scenario where both types of storage are used in equilibrium along with wind and solar generation. This figure is analogous to Figure 4. Electricity discharged from storage is used to smooth generation and consumption before and after the middle of the day, with generation peaking around noon. Because the dashed line represents the average consumption,

9 https://emp.lbl.gov/sites/default/files/2024-04/Queued%20Up%202024%20Edition_R2.pdf

10 Johnston, Liu, and Yang, "An Empirical Analysis of the Interconnection Queue."

Figure 11: Storage Demand Relative to Original Capital Cost



Results from simulation of long-run investment under various assumptions about decreases in capital costs for generating electricity from renewable sources and about adopting a carbon tax of $100 per metric ton. The capital costs of each type of storage are varied in each scenario to create the demand curves. The relative price on the y-axis is the percentage of the current price relative to the original, with 100% reflecting the original price.

this highlights how storage can be used to transfer electricity generated in peak generation hours to peak consumption hours. While renewables contribute to most of the electricity generated, gas is still used to help generate electricity in off-peak renewable hours.

Finally, Figure 11 shows that demand for energy storage increases dramatically as energy storage capital costs decrease. Across all scenarios, for both storage types, the marginal increase in quantity demanded increases as storage prices decrease. The effect is especially pronounced once short-duration capital costs reach $5,000 per MWh and long-duration capital costs reach $10,000 per MWh. In fact, marginal returns to capital cost decreases early on appear quite low.

Our model indicates that energy storage cost has not yet hit the critical threshold at which point it will gain wide usage. The model predicts significant increases in the share of renewable energy if the capital costs of energy storage technologies decrease by around 50% or if a carbon tax is introduced. One way to decrease the cost of energy storage is to develop technological breakthroughs that provide cost-effective and efficient storage. Research and development efforts that move from fundamental understanding to technology development and commercialization could play a critical role. In the following sections, we provide an overview of energy storage research activities and identify opportunities to accelerate the deployment of energy storage technologies.

06. CURRENT STATUS OF ENERGY STORAGE RESEARCH IN NORTH CAROLINA

In this section, we analyze the current status of energy storage research in academic and non-academic (government and private sector) settings. We summarize research operations in batteries, synthetic fuels, and supercapacitors within each setting, with a focus on the past 10 years. We consider these the key areas where research and technology development could lead to significant capital cost reduction for energy storage.

The goal of the analysis is to understand which organizations are already engaged in energy storage research and to analyze the extent of the activities and their geographic distribution across the state. The analysis also provides comparisons of research activity between the energy storage fields of batteries, synthetic fuels, and supercapacitors.

We developed an analytical methodology to identify academic and non-academic organizations conducting energy storage research, and we expand on the details for academic and non-academic settings in the following sections. For both settings, we identified a set of 5-10 keywords for each field and used those consistently to identify active organizations based on their publication records, grants awarded, and company descriptions. After identifying individual researchers at universities or individual companies operating in North Carolina, we used location information and temporal data to generate time-dependent growth analysis and spatial mapping of where activities are happening in the state.

ACADEMIC RESEARCH (COLLEGES AND UNIVERSITIES)

To identify energy storage research activities in academic settings, we followed the methodology outlined in Figure 12. First, we manually identified investigators using publicly available information on the websites of academic institutions. National Center for Education Statistics data shows 58 four-year public and private colleges and universities in North Carolina. Of these, 26 have science or engineering departments. Within those 26 institutions, we identified 172 total departments or other academic units that could reasonably house any type of science, mathematics, or engineering research. We manually searched public biographies to identify all faculty who might reasonably be engaged in research relevant to energy storage, identifying 172 investigators across 18 institutions in North Carolina. This manual approach emulates what someone looking for academic researchers on public websites might find. Engineering-related schools and departments housed a plurality of the investigators found through this method (~48%), followed by chemistry-related departments (~36%).

Next, we employed the research database Dimensions to quantify the academic publications in North Carolina (and across the United States) focused on energy storage. We limited our search to publications within the past 10 years that include in the title or abstract any of 5-10 keywords for each of three storage fields: batteries, synthetic fuels, and supercapacitors. See Table 3 for the full list of keywords. We used relevant physical science and engineering research topic filters to mitigate false positive hits such as publications that contain phrases like "…*battery of tests*…" in their abstracts. This approach gave us insight into which fields were most actively studied. In parallel, we analyzed the Dimensions grant database in an analogous fashion. The result is a dataset with investigator, date, location, and research field information across North Carolina.

In the past 10 years, North Carolina researchers have published approximately 780 articles related to aspects of battery technology. This research has been fueled by 55 federal or state grants totaling

Figure 12: Methodology for Assessing Academic Activity in Research and Development of Batteries, Synthetic Fuels, and Supercapacitors

58 four-year public and private NC universities

↓

26 universities with science or engineering units

↓

172 STEM-related departments or units in 53 Colleges or Schools

↓

172 faculty in those departments that highlight energy storage keywords in faculty pages/websites

Dimensions reports by energy storage keywords to obtain publication and grant information from 2015 – 2025

↓

Geospatial mapping in ArcGIS to visualize NC university publication and funding landscape in energy storage research

The figure shows on the left the workflow that identified 172 faculty active in energy storage fields of batteries, fuels, and supercapacitors, moving from the institutional level to schools/departments. On the right, the search methodology using keywords to identify publications and grants to North Carolina institutions is summarized.

over $24M. North Carolina State University (NCSU) is the most active player in battery research in the state, followed by the University of North Carolina at Charlotte (UNC-C), Duke University, and the University of North Carolina at Chapel Hill (UNC-CH).

Over the same 10-year period, more publications (about 970) related to fuels have been published. The grant support for fuels is robust, with 119 total grants worth more than $130M. NCSU is again leading in fuel research publications, with UNC-CH and Duke also highly active contributors. UNC-CH has led a number of major grants in the fuel space.

Supercapacitor research is not as active in North Carolina, with only approximately 170 publications in the past 10 years. Three grants worth $1.5M support this research. The University of North Carolina at Greensboro (UNC-G), Duke, North Carolina Agricultural and Technical State University (NCA&T), and NCSU are key players.

NON-ACADEMIC RESEARCH (GOVERNMENT AND PRIVATE SECTOR)

We applied the methodology from Figure 13 to identify energy storage research activities in non-academic settings. Given our focus on research and development, we made every effort to exclude entities that are solely manufacturing, repair, or sales. We took two parallel approaches to maximize the number of companies identified: one based on publicly available company descriptions and the other based on federal grants awarded to companies. These approaches are complementary because new startups may have received grant funding but have not yet been indexed by company classification systems.

We used North American Industry Classification System (NAICS) codes, which classify businesses by their industry and subsectors, to identify relevant companies operating in North Carolina. We then used Reference Solution's Data Axle platform to search for relevant NAICS codes and company locations. The database only includes companies that are headquartered or have physical locations in North Carolina as of the last database update. First, we obtained the NAICS codes of known relevant companies (e.g. Albemarle and Piedmont Lithium). Then we used keywords (solar, energy, storage, battery, renewable, research, engineer, chemical, environmental) to find additional relevant NAICS codes. Next, we conducted a search using all collected relevant NAICS codes in Data Axle. The results included companies where the relevant NAICS codes matched any one of their codes (i.e., primary, secondary, tertiary, etc.). We exported the results, including each company name, their city location, and their primary NAICS code, and after manually discarding companies with irrelevant primary codes, we researched each company individually to determine whether the company was involved in research and development in the energy storage fields of interest. Finally, we categorized the relevant companies as batteries, fuels, or supercapacitors.

We identified grants awarded to companies in North Carolina using Dimensions in a manner almost identical to that described for the academic institutions. We obtained all grants awarded to companies in North Carolina over the past 10 years from Dimensions queries and identified the relevant grants by searching with the 5–10 keywords for each energy storage field. The resulting dataset provided the company, award dates, location, and research field.

We found a total of 43 companies participating in renewable energy storage research and development after cross-referencing the grants and NAICS code results. Twenty-seven of these companies are focused on batteries, primarily lithium-ion, and the other 16 on fuels, including hydrogen and biofuel. Notably, we did not find any companies conducting research on supercapacitors, which indicates an area of research that North Carolina has yet to capitalize on. The next section contains heat maps that visually represent the locations of companies performing energy storage research. We constructed different heat maps for each category to visually compare where each type of research is taking place. The heat map showcasing only companies focused on researching batteries suggests a greater concentration of battery research in the Charlotte and Triangle areas in comparison to the rest of the state. The fuel research companies are less concentrated but still operate mainly near Charlotte or the Triangle.

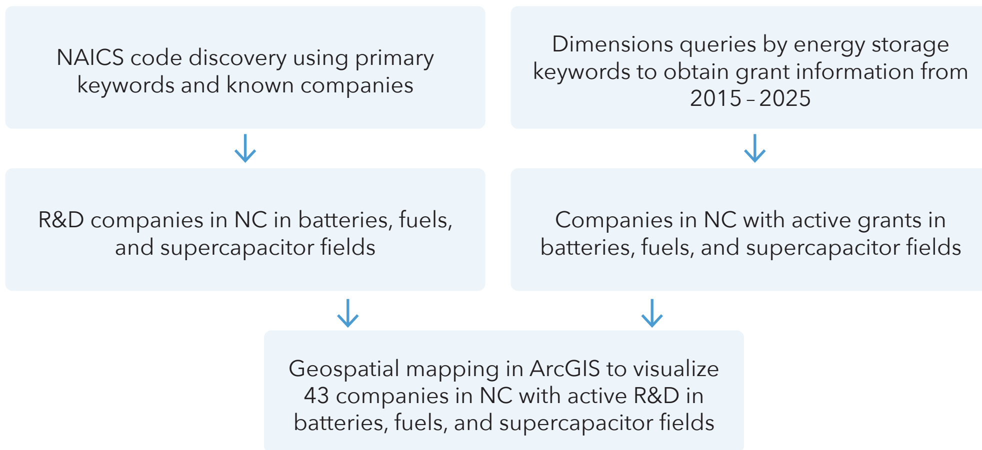
TRENDS AND OPPORTUNITIES IN CURRENT ENERGY STORAGE RESEARCH IN NORTH CAROLINA

The above analysis provides valuable insight into the current landscape of energy research in North Carolina. This section summarizes the broader findings that emerge from the study and highlights opportunities for further development.

We visualize the aggregated publication and grant data for academic institutions in Figure 14, separated into batteries, fuels, and supercapacitors. The green circles represent grant funding, with larger circles representing more grant funds allocated in that location. The colored circles represent the number of publications, with lighter colors for lower publication counts and darker colors for higher publication counts. Readers interested in viewing similar maps broken down by the additional keywords within each energy storage area can access the data online (see Appendix).

The maps show there is currently more activity in battery and fuel research than in superconductors. UNC-C has a high number of publications relative to the amount of grant funds the institution has received for battery research. While some trends are clear, there are limitations in our ability to draw conclusions because the map does not capture university or state investments or gifts. Furthermore, grant award databases usually only note the primary award location, even if funds move elsewhere. For example, UNC-CH has served as the headquarters for two large collaborative grants in the synthetic fuels space. The grant funding at UNC-CH is therefore enormous in the fuels plot and does not reflect the fact that a significant fraction of the UNC-CH funds have supported research at Duke, NCSU, and partner institutions outside North Carolina.

Figure 13: Methodology for Discovering Businesses Involved in Research and Development of Batteries, Synthetic Fuels, and Supercapacitors



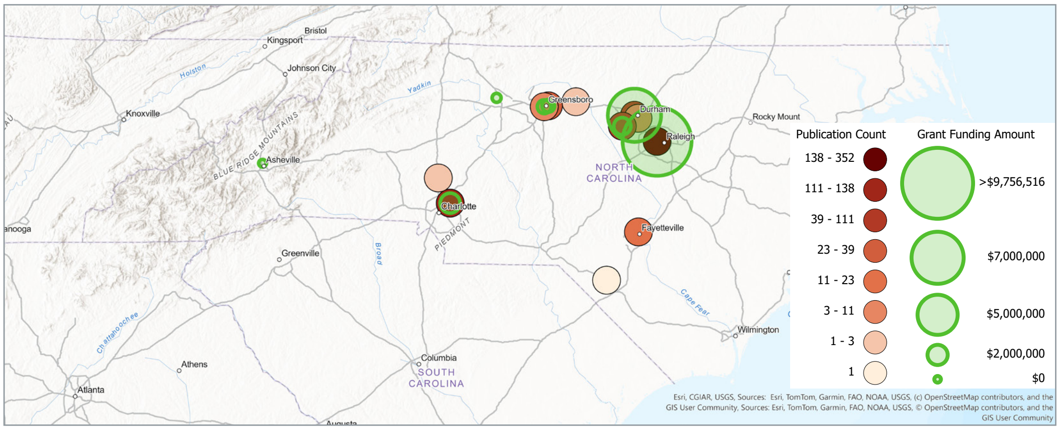
The figure shows on the left the workflow that identified 43 companies active in energy storage fields of batteries, fuels, and supercapacitors, based on NAICS code discovery. On the right, the search methodology using keywords to identify grants to North Carolina companies is summarized.

Figure 15 shows the change in annual publication count in each energy storage area over the past 10 years. The number of publications on supercapacitors is relatively small, so drawing conclusions is difficult. NC-based batteries and fuels publications have slightly trended upward since 2015. Notably, however, there are several areas such as lithium-ion batteries and biofuels have trended slightly downward over the last 10 years. It is hard to speculate on the origin of the trend, but it is worth watching carefully.

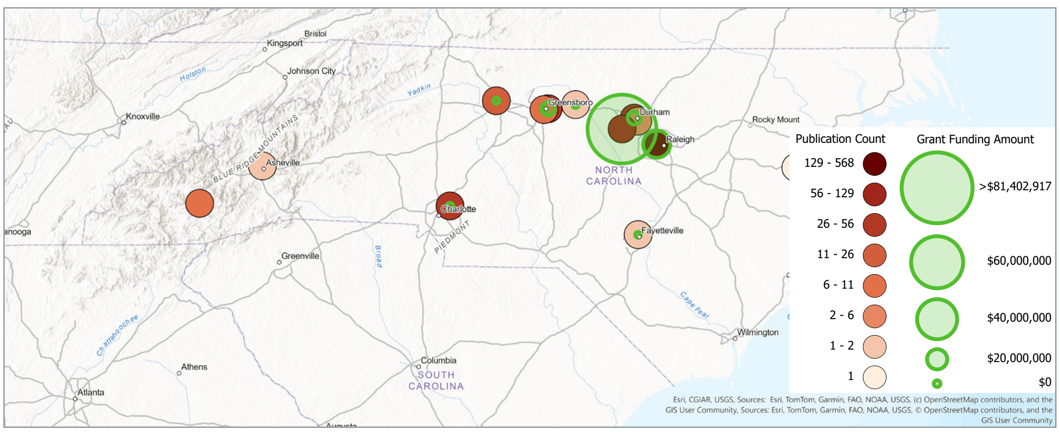
We identified several companies that are highly active in energy storage research using our methodology. Albemarle Corporation, headquartered in Charlotte, has a Lithium Conversion Facility in Kings Mountain near one of the region's richest spodumene ore deposits. As mentioned in the earlier SPOTLIGHT, they are currently pursuing efforts to leverage their strategic placement to restart extraction of these critical local resources to strengthen domestic supply chains. Piedmont Lithium, to the north in Gaston County, is planning an integrated lithium project that would combine mining, spodumene concentrate production, and lithium hydroxide conversion in the same site, which would be the world's only fully integrated lithium site. Soelect, operating out of Greensboro, was founded in 2018 and is pioneering solid-state lithium battery technologies that have safety and productivity advantages over traditional lithium-ion batteries. Of note, Soelect's cofounder was formerly the director of the Joint Center of Nanoscience and Nanoengineering (JSSN) Nanoenergy program – highlighting the opportunities and technological innovations that can be incubated in the collaborative North Carolina universities. Based out of Durham, 8 Rivers focuses their research and development on infrastructure-scale technologies aimed at lowering harmful emissions and lowering net CO_2 concentrations in the atmosphere and in industrial processes. While they have several efforts in carbon capture technology, the energy storage technology most relevant for this report is a method that uses innovative combustion techniques to produce hydrogen fuel more efficiently.

There are some opportunities that appear when looking at the data on current research in academia. Because battery research is currently dominated by

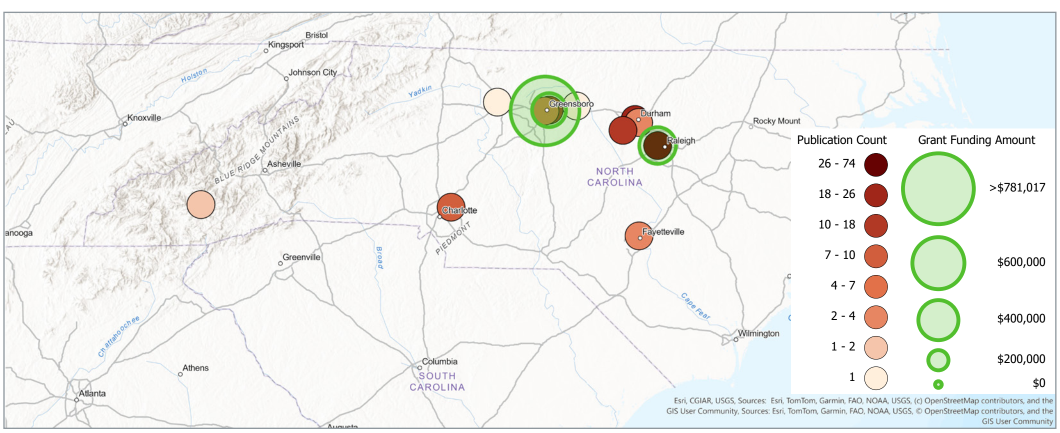
Figure 14: Geographical Distribution of North Carolina Academic Publications and Grants



(a) Batteries



(b) Fuels



(c) Supercapacitors

Three maps show how publications and grants are distributed across academic institutions in North Carolina with separate plots for the three energy storage fields of batteries, fuels, and supercapacitors. High publication counts and large amounts of grant funding are noted in the Research Triangle, Greensboro, and Charlotte.

WE ANTICIPATE INCREASED BUSINESS ACTIVITY IN SOLAR ENERGY CONVERSION AND BATTERY RESEARCH AND MANUFACTURING BECAUSE OF THE NATURAL RESOURCES FOUND IN NORTH CAROLINA.

engineering departments at UNC-C, NCSU, and Duke, there should be opportunities for more fundamental studies in non-engineering departments (e.g. UNC-CH) that can synergistically feed new developments into established engineering scale-up efforts. Fayetteville State has established itself as a rising player in the state, providing an opportunity for more engagement with other institutions. Because solar fuels are dominated by UNC-CH and NCSU chemistry, there should be opportunities for engineers at these and other institutions to investigate the large-scale feasibility of these new technologies. Supercapacitor research is also dominated by engineering; are there opportunities in physical and materials chemistry or other more fundamental areas?

We also found that large teams doing collaborative research have pushed the research frontier in batteries and fuels. As shown in the SPOTLIGHT, the Department of Energy has supported large collaborative energy centers headquartered at UNC-CH and involving collaborators at NCSU and Duke. These activities can be enhanced by locally supported research infrastructure that is used by the teams but also other researchers within and outside of the university. The UNC-CH Sustainable Energy Research Consortium (SERC) serves this role for the main grant in its portfolio (CHASE, see SPOTLIGHT below) as well as for smaller teams with interest in battery research, fostering collaboration and providing continuity in instrumentation support. At UNC-C, the North Carolina Battery Complexity, Autonomous Vehicle and Electrification Research Center (BATT CAVE)[1], built on a $40M investment by the NC General Assembly in 2021, provides a state-of-the-art testing facility and network of laboratories at the forefront of battery research. The BATT CAVE has leveraged UNC-C's multitude of industry connections and cross-disciplinary engineering expertise to address emerging technologies in electric vehicles and battery safety. At UNC-G, the recently established Battery Research, Innovation, and next-Gen Energy Harvesting Technologies (BRIGHT) Institute[2] aims to translate bench scale innovations to pre-commercial pilots and demonstrate the self-sufficiency of the state's battery supply chain through workforce development and regional partnerships.

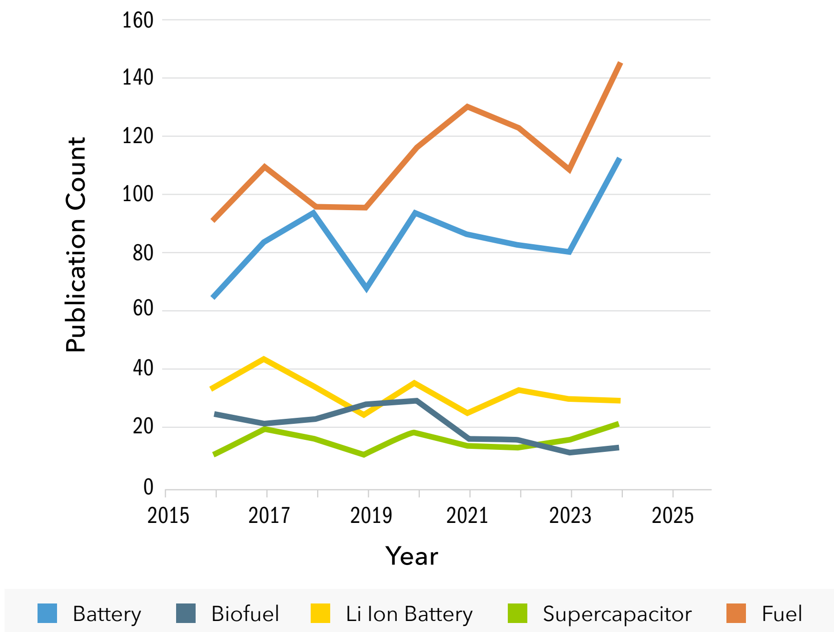
Turning to companies engaged in energy storage research and development, Figure 16 shows the geographic distribution and number of companies related to battery and fuel research and development in North Carolina. The lighter colors represent fewer companies, while the darker colors represent more companies at that location. There are numerous companies in both sectors in the Research Triangle region. There is more business activity in fuels research in Wilmington, however, while there is more battery activity in the region surrounding Charlotte.

We anticipate increased business activity in solar energy conversion and battery research and manufacturing because of the natural resources found in North Carolina. As noted above, North Carolina enjoys a high number of sunny days and has built impressive infrastructure for solar energy generation, and large lithium reserves are driving investments in the battery sector.

1 https://battcave.charlotte.edu/

2 https://bright.uncg.edu/

Figure 15: Publication Count Over Past Decade



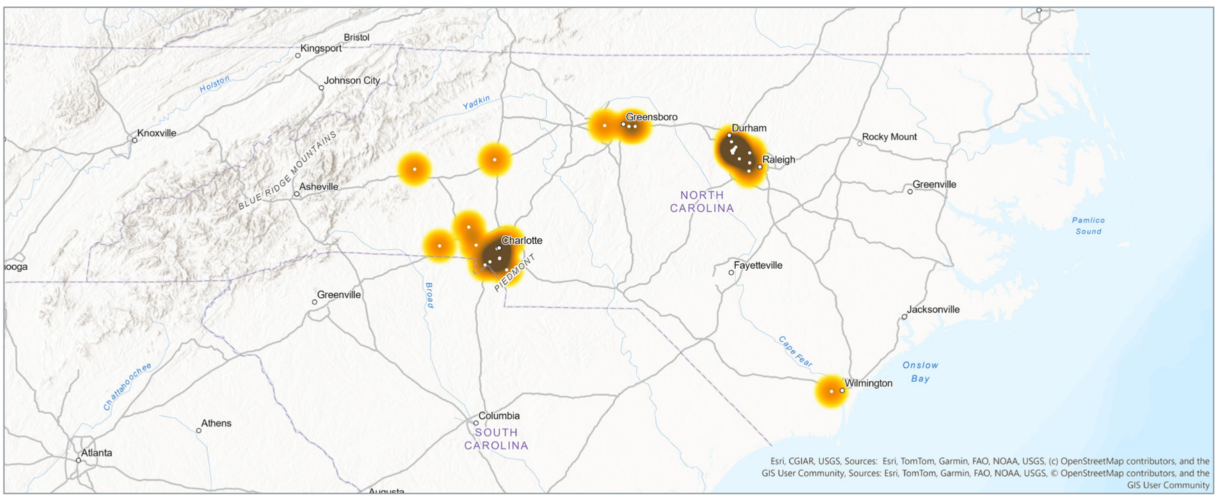
Publications in each year from 2016 to 2024 with at least one author affiliated in North Carolina and an academic affiliation and containing specific energy storage keywords. Data obtained using the methodology described in the text.

The publications and grants databases enable comparisons of energy storage research activity across states. Table 3 summarizes North Carolina's ranking in each of the keywords in terms of publication activity and grant dollars. In battery science, North Carolina generally ranks in the top half of all states in terms of both publication activity and grants – but in no category is the state ranked in the top 10. This represents a clear opportunity for growth, especially considering the important lithium reserves in the state and the growing number of companies active in this area. In fuels, however, North Carolina ranks in the top 10 in many categories. In solar fuels, North Carolina is ranked number 2 in the nation in grant funding, and in fuel research involving CO_2, the state is ranked number 1 in the nation in grant funding. Enacting the recommendations below can help ensure that North Carolina maintains a leadership role in the storage of solar energy, an area that complements the state's leadership in solar electricity generation.

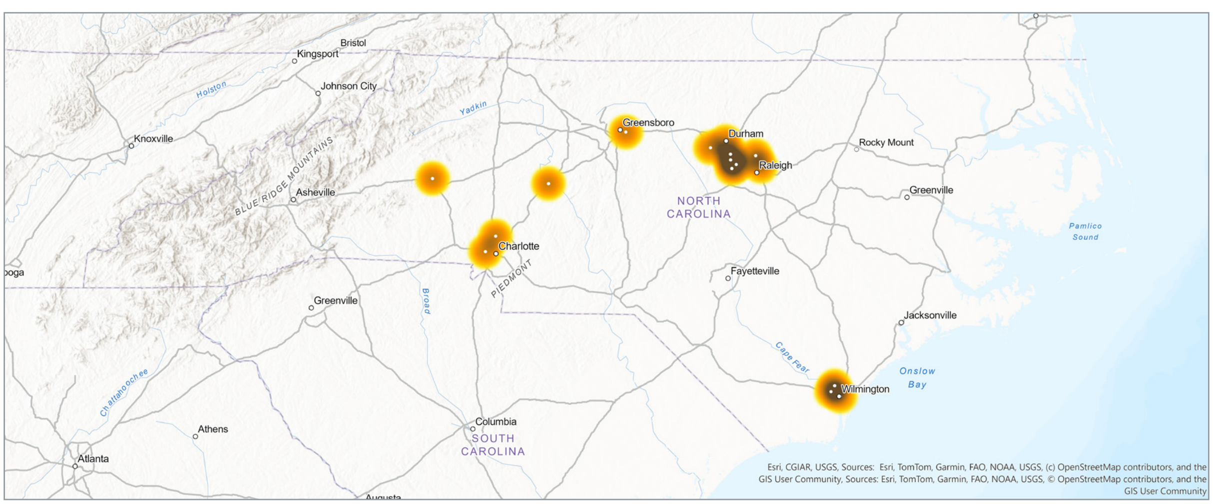
In summary, our analysis establishes several areas of strength in energy storage research in North Carolina while also identifying challenges. There is an active base of energy storage research spanning from fundamental to applied sciences in North Carolina, including some large-scale collaborative projects. The state therefore has the key ingredients to be a national leader in energy storage research. There are clear opportunities, however, to enhance energy storage research by expanding collaborations, especially between basic sciences and engineering fields and between academia and industry. A particularly concerning challenge is that the rate of publication in energy storage fields has been declining in recent years. The following section provides recommendations that could help address these challenges and elevate North Carolina to the premier state for energy storage research in the United States of America.

THERE ARE CLEAR OPPORTUNITIES, TO ENHANCE ENERGY STORAGE RESEARCH BY EXPANDING COLLABORATIONS, ESPECIALLY BETWEEN BASIC SCIENCES AND ENGINEERING FIELDS AND BETWEEN ACADEMIA AND INDUSTRY.

Figure 16: Geographical Distribution of North Carolina Companies Involved in Energy Storage Research



(a) Batteries



(b) Fuels

Two maps show how companies with research and development in batteries (a) and fuels (b) are distributed across North Carolina.

SPOTLIGHT

COLLABORATIVE ACADEMIC ENERGY RESEARCH

Beginning in 2009, the Department of Energy has invested heavily in solar fuels research in North Carolina. Three phases of Energy Frontier Research Centers (EFRCs) have been headquartered at UNC-CH, the funding for which totaled over $30M. At various stages, UNC EFRC partner institutions have included NCSU, Duke, and NC Central University. These EFRCs collectively resulted in over 300 publications, 6 U.S. patents, hundreds of scientists trained, and established UNC-CH as a national leader in solar energy conversion to storable fuels. In 2020, UNC-CH was awarded a larger, $40M 5-year grant, the Center for Hybrid Approaches in Solar Energy to Liquid Fuels. While the methodologies and specific research efforts have evolved over the last decade and a half, the overarching goal of these Centers has been to perform fundamental research towards harvesting solar energy and using that energy to drive the transformation of molecules like carbon dioxide and/or water into usable, storable, chemical fuels. The EFRC and CHASE programs, managed under the UNC-CH SERC (formerly Solar Energy Research Center) have also resulted in robust institutional infrastructure that is now being extended into cutting-edge facilities for fundamental and applied battery fabrication and testing research.

Table 3: North Carolina's National Ranking in Number of publications, Number of Grants, and Grant dollars

Category	North Carolina Ranking
Battery Publication	17 out of 50
Battery Grant Count	15 out of 50
Battery Grant Amount	24 out of 50
Lithium-Ion Battery Publication	16 out of 50
Lithium-Ion Battery Grant Count	20 out of 46
Lithium-Ion Battery Grant Amount	21 out of 46
Sodium-Ion Battery Publication	14 out of 50
Sodium-Ion Battery Grant Count	13 out of 34
Sodium-Ion Battery Grant Amount	15 out of 34
Solid Battery Publication	18 out of 50
Solid Battery Grant Count	20 out of 49
Solid Battery Grant Amount	25 out of 49
Cathode Material/Anode Material Publication	22 out of 50
Cathode Material/Anode Material Grant Count	24 out of 43
Cathode Material/Anode Material Grant Amount	25 out of 43
Battery Electrolyte Publication	18 out of 45
Battery Electrolyte Grant Count	14 out of 45
Battery Electrolyte Grant Amount	18 out of 45
Battery Safety Publication	15 out of 48
Battery Safety Grant Count	16 out of 48
Battery Safety Grant Amount	23 out of 48
Fuel Publication	16 out of 50
Fuel Grant Count	12 out of 50
Fuel Grant Amount	10 out of 50
Fuel CO_2/Carbon Dioxide Publication	11 out of 50
Fuel CO_2/Carbon Dioxide Grant Count	8 out of 46
Fuel CO_2/Carbon Dioxide Grant Amount	1 out of 46

Table 3 (Continued): North Carolina's National Ranking in Number of Publications, Number of Grants, and Grant Dollars

Category	North Carolina Ranking
Hydrogen Evolution Publication	19 out of 50
Hydrogen Evolution Grant Count	15 out of 43
Hydrogen Evolution Grant Amount	9 out of 43
Ammonia Publication	19 out of 50
Ammonia Grant Count	15 out of 44
Ammonia Grant Amount	24 out of 44
Solar Fuel Publication	8 out of 49
Solar Fuel Grant Count	8 out of 47
Solar Fuel Grant Amount	2 out of 47
Fuel Electrocatalytic/Electrocatalysis Publication	24 out of 48
Fuel Electrocatalytic/Electrocatalysis Grant Count	11 out of 39
Fuel Electrocatalytic/Electrocatalysis Grant Amount	11 out of 39
Biofuel Publication	12 out of 50
Biofuel Grant Count	12 out of 49
Biofuel Grant Amount	24 out of 49
Water Splitting Publication	10 out of 49
Water Splitting Grant Count	10 out of 41
Water Splitting Grant Amount	10 out of 41
Supercapacitor Publication	10 out of 48
Supercapacitor Grant Count	15 out of 34
Supercapacitor Grant Amount	14 out of 34
Carbon Supercapacitor Publication Rank	9 out of 48
Carbon Supercapacitor Grant Count Rank	14 out of 20
Carbon Supercapacitor Grant Amount Rank	17 out of 20
Oxide Supercapacitor Publication Rank	9 out of 47
Oxide Supercapacitor Grant Count Rank	2 out of 15
Oxide Supercapacitor Grant Amount Rank	5 out of 15

Not every state had publications or grants in every category, and thus not every ranking is out of all 50 states. Thus, the ranking out of the states that have >0 publications and grants for each keyword/subkeyword is given.

07. RECOMMENDATIONS

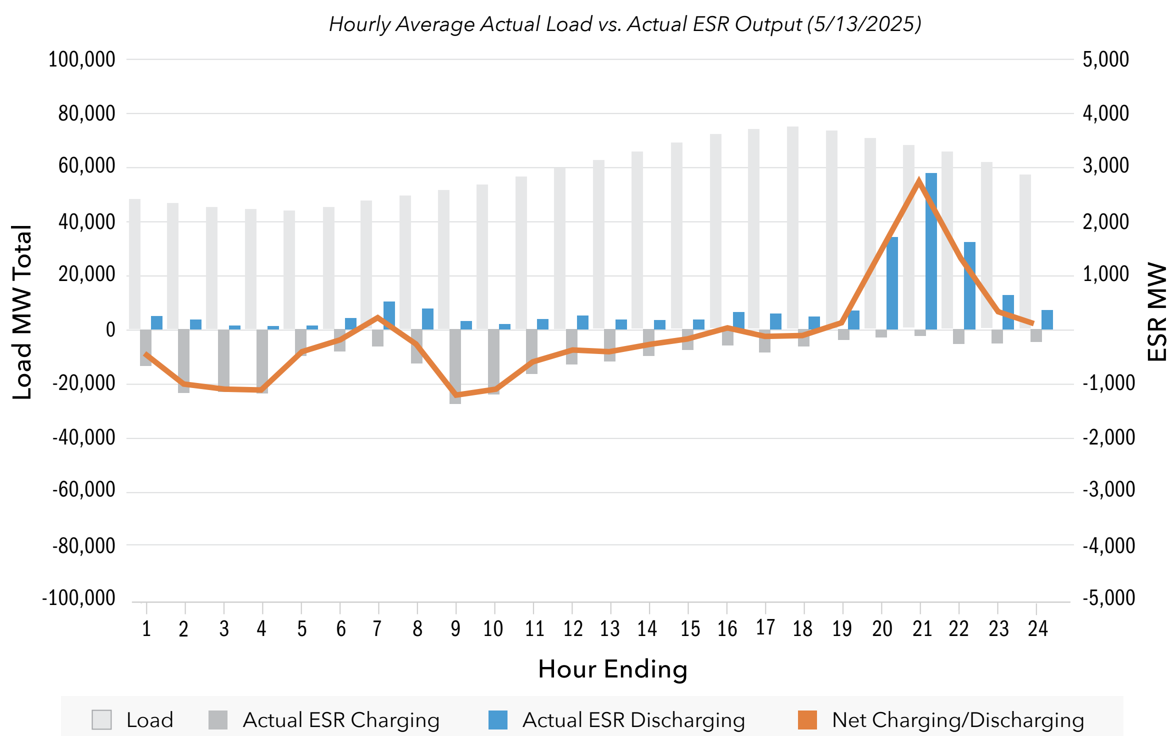
Recommendation 1

Make better energy data available for NC

Charting the next steps for storage in the Carolinas requires knowing where the starting line is. While public data sources have useful aggregate information on storage in the Carolinas, detailed information is neither available nor recorded anywhere. On a day-to-day level, it is unclear whether storage is charging or discharging.

Grid operators in other regions have made this information readily available. ERCOT, the grid operator for most of Texas, has real-time dashboards about the share of energy that storage is providing at any moment and daily summaries, one of which is shown in Figure 17. The daily summaries show, each hour, how much storage is charging and discharging. They also illustrate what share of total possible storage in the region is being charged and discharged.

Figure 17: Sample Day of Storage Charging and Discharging in Texas



This figure shows storage charging and discharging in Texas on May 13th, 2025. The light grey bar indicates the energy demand in Texas. Dark grey bars indicate storage resources that are charging, while blue bars indicate storage that is discharging. Storage facilities charge during the day, when renewable energy is plentiful, and discharge in the evening when demand is high and renewable energy is limited. Discharging as a percentage of total discharging available in Texas peaked at 24% at 9PM CDT.

Source: https://www.ercot.com/mp/data-products/data-product-details?id=NP4-765-ER

North Carolina would benefit from data availability leadership. Our study makes clear that short- and long-duration storage is coming to North Carolina's grid. Making good policy decisions – whether they result from implementing a carbon tax, incentivizing construction of certain technologies, or something else – will rely on knowing how storage is being used in the state.

Recommendation 2

Enhance investments in long-duration storage

Both long- and short-duration storage would benefit from more research and development efforts. Solar and wind facilities are currently being installed at high rates across the country. Storage capabilities are also being installed, even with current capital costs. Most of the storage that has been built is short-duration storage though. Our model shows that long-duration storage would be very useful for firms if its costs came down: 80% decreases in the cost of long-duration storage could lead to much wider adoption of long-term storage. Such cost decreases are reasonably achievable for nascent technology like flow batteries with increased support. North Carolina is well-positioned to be a leader in these research and development efforts: as research in economics has shown, innovation spillovers are significant for companies and researchers located in the same area.[1] Our review of academic and commercial activities in North Carolina shows that networks exist for ideas to spread.

Recommendation 3

Establish mechanisms for basic science researchers to communicate and collaborate with applied scientists

The chemists, physicists, biologists, and researchers from other fields that are active in basic research can benefit tremendously from collaborations with engineers and other applied scientists. Workshops and conferences that bridge fundamental and applied science can help strengthen the network. Seed funding proposals that require collaboration can also spark movement in this direction. The outcome of these efforts would be more publications and faster translation of basic science findings to technologies.

Recommendation 4

Invest in shared user facilities for energy storage research

Core laboratory user facilities in universities can serve as nucleation points for research. If a researcher has an idea that can impact energy storage technology, they are more likely to pursue that idea if barriers to entry are low. Having nearby shared user facilities helps ensure that a researcher does not need to make large financial investments in instrumentation and large time investments in training to try new ideas. Shared user facilities are also generally open to the public

1 See, e.g., Matray (2021).

and can help startup companies get off the ground and remain nimble. This recommendation can also help enhance the publication rate of more established researchers by providing instrumentation access and expert assistance to accelerate research.

Recommendation 5

Invest in metal-ion battery workforce development and innovations, including industry-academic partnerships

The presence of lithium resources and the trend in battery companies investing in North Carolina suggests that our higher institutions have a great opportunity to train the future leaders of these companies. New programs that provide adequate training to meet the future energy workforce needs would be valuable. Partnerships between academic programs and local businesses can help shape these programs. Incubator spaces in universities can help convert promising laboratory scale findings into startup companies or licensed technologies. In the SPOTLIGHT there are two recent successful industry-academic partnerships, which can provide a model to follow.

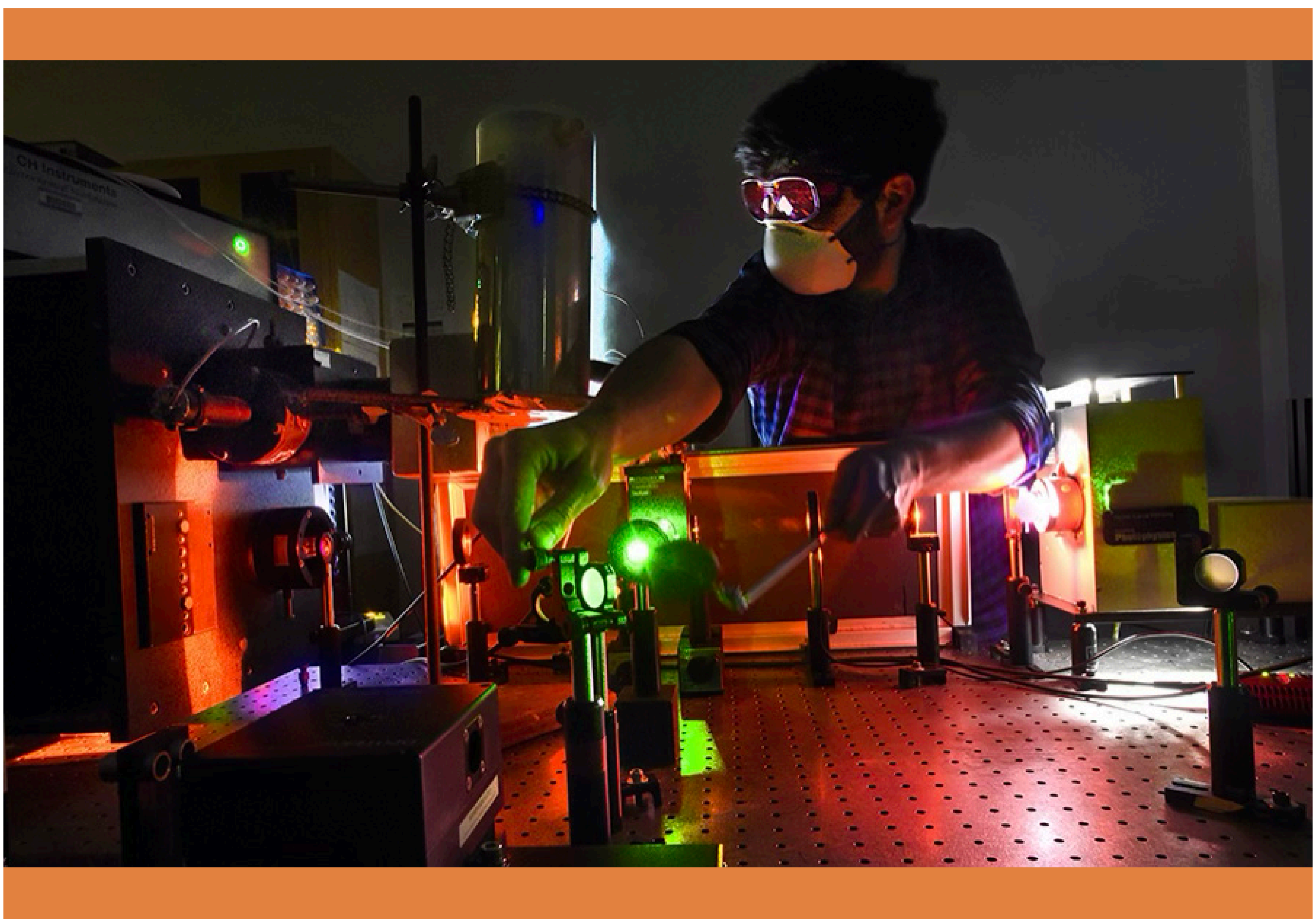


Photo credit: Donn Young

SPOTLIGHT

INDUSTRY/ACADEMIC PARTNERSHIPS

Eastman Chemical Company established a Center of Excellence with NCSU and UNC. Eastman is headquartered in Eastern Tennessee but established an office in Raleigh and has invested heavily in NC academic institutions. This has led to technological development, workforce training, and advances in a range of sectors. In the Piedmont Triad area, shortly after Toyota Battery Manufacturing announced their investment in their first EV production plant in the US just outside Liberty, NC (which is producing North American EV batteries as of March 2025), several significant grants to NCA&T and Communities in Schools of Randolph County were given by Toyota to boost workforce readiness and expand STEM education in the state.

Source: https://www.ncat.edu/news/2022/09/toyota-donates-500k.php

Photo credit: Alyssa LaFaro / UNC Research

08. APPENDIX: ADDITIONAL DATA

a. Publications and grants data

i. Example Dimensions search parameters for publication information:

- Criteria: 'battery' in title and abstract;
- Publication Year is 2025 or 2023 or 2024 or 2022 or 2021 or 2020 or 2019 or 2018 or 2017 or 2016;
- Organization type is Education;
- Country/Territory is United States;
- State/Region is North Carolina;
- Fields of Research (ANZSRC 2020) is 3106 Industrial Biotechnology or 34 Chemical Sciences or 3702 Climate Change Science or 3703 Geochemistry or 40 Engineering or 41 Environmental Sciences or 51 Physical Sciences or 4901 Applied Mathematics;
- Publication Type is Article;
- Document Type is not Correction Erratum and not Other Journal Content and not Conference Abstract and not Editorial and not Letter To Editor and not Book Review.

ii. Example Dimensions search parameters for grant information:

- Criteria: 'battery' in title and abstract;
- Start Year is 2025 or 2023 or 2024 or 2022 or 2021 or 2020 or 2019 or 2018 or 2017 or 2016;
- Organization type is Education;
- Organization type is not Company;
- Country/Territory is United States;
- State/Region is North Carolina; Fields of Research (ANZSRC 2020) is 3106 Industrial Biotechnology or 34 Chemical Sciences or 3702 Climate Change Science or 3703 Geochemistry or 40 Engineering or 41 Environmental Sciences or 51 Physical Sciences or 4901 Applied Mathematics.

iii. The Dimensions reports for the above queries for each keyword and subkeyword can be found here in the UNC Dataverse: https://doi.org/10.15139/S3/L6ABV3

b. ArcGIS map: https://unc.maps.arcgis.com/apps/instant/basic/index.html?appid=fef18386baa84420bfc797f0527ca814

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FUNDING

North Carolina Collaboratory

We would like to thank the following stakeholders for valuable oversight and feedback on this report:

- **John Hardin**, Executive Director, Office of Science, Technology & Innovation, NC Department of Commerce
- **Jeff Warren**, Executive Director, North Carolina Collaboratory

https://doi.org/10.17615/vwxx-1r45

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