6. New Supply-Side Resources

Highlights

- *Large scale wind resources exhibit the lowest cost on a levelized cost of energy (LCOE) basis among all candidate resource options without tax incentives.*
- *With federal investment tax credits (ITC) or production tax credits (PTC), large scale solar resources closely follow wind resources as low-cost energy resources in addition to providing significant summer peak capacity benefits.*
- *Battery storage has been identified as a candidate resource option in addition to pumped storage.*
- *Ameren Missouri selected three natural gas technologies as final candidate resource options – Gas Combined Cycle with and without carbon capture and sequestration (CCS), and Gas Simple Cycle Combustion Turbine. Gas Combined Cycle exhibits the lowest LCOE among non-renewable generation resources.*

The supply-side screening analysis of various coal, gas, and renewable power generation technologies used in the 2020 IRP was reviewed by Ameren Missouri subject matter experts and updated for use in the 2023 IRP. Supply chain constraints and challenges have created upward pressure on wind and solar technology unit-costs, but to a large extent these challenges have been offset by extended and expanded tax credits included in the 2022 Inflation Reduction Act (IRA). Other incentives in the IRA also make the use of hydrogen and carbon capture and sequestration projects more attractive than they have been in the past. This IRP focuses on solar, wind, storage, and natural gas (both simple cycle and combined cycle) as potential new supply-side resources. Nuclear generation is also included due to its ability to provide around-the-clock carbon-free energy.

Ameren Missouri continues to monitor the universe of storage resource options, including pumped hydro storage, compressed air energy storage (CAES), stacked blocks (gravity storage), liquid air, and several battery energy storage system (BESS) technologies. Pumped hydroelectric storage is still an energy storage resource included in our evaluation of alternative resource plans as a major supply-side resource. However, with the advancements in BESS, including various lithium-ion and flow battery technologies, and the challenges associated with permitting new pumped hydroelectric storage facilities, BESS is the primary energy storage resource included as a major supply-side resource in the near to medium term.

While some energy storage technologies have not been selected for integration analysis, it is important to note that the use cases for such technologies continue to develop, as does the consideration of appropriate market treatment for the services that these

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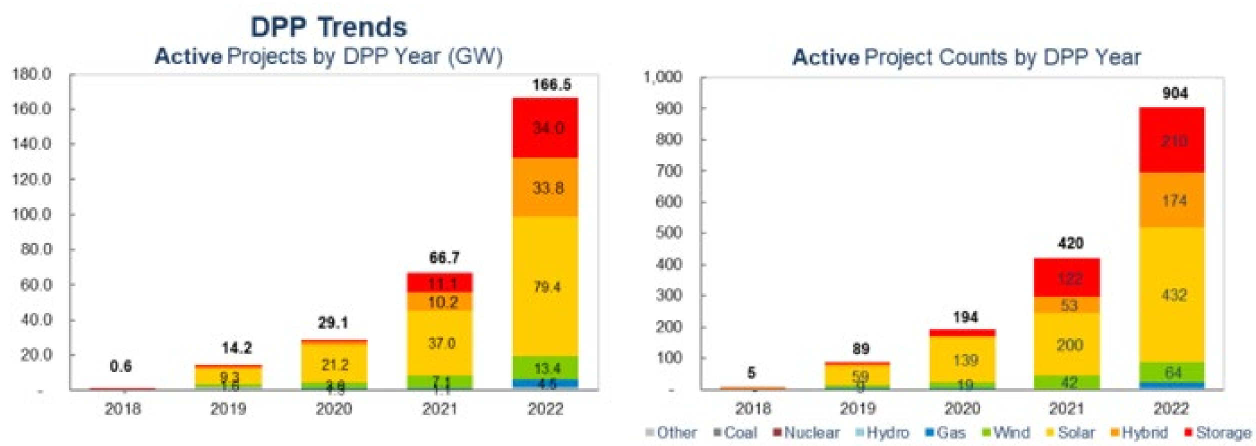
technologies can provide. Such ongoing developments will continue to be considered as part of our ongoing resource planning, including consideration of technologies and services provided by and to the transmission and distribution systems.

Capital costs for all preliminary candidate supply-side options include any necessary transmission interconnection costs. No preliminary candidate supply-side resource option was eliminated from further consideration due to interconnection or other transmission analysis.[1]

6.1 Potential Renewable Resources[2]

As of March 2023, the Midcontinent Independent System Operator (MISO) shows a year-over-year increase across all renewable technology generation interconnection (GI) requests. Although wind project GI requests ticked meaningfully upwards in 2022, they are still far outnumbered by solar projects by both project count and total capacity. 2022 also saw an increase in the number of storage project GI requests, from 122 projects in 2021 up to 210 in 2022. All GI requests proceed through the Definitive Planning Phase (DPP) process as MISO and the appropriate transmission owners evaluate how the generation projects will affect the bulk electric system. Figure 6.1 shows DPP trends by year, in terms of both capacity (left) and project count (right).

Figure 6.1 MISO Generator Interconnection: Overview[3]



There are a total of three DPP iterations, and GI requests may proceed to the next phase or be withdrawn depending on business case decisions for each project. The recent extension of federal tax credits for wind, solar, and storage through the IRA is expected to further accelerate the development of these resources across MISO, as seen already in the large increase in projects in the queue in 2022. A detailed characterization of the

[1] 20 CSR 4240-22.040(4)(B); 20 CSR 4240-22.040(4)(C)
[2] 20 CSR 4240-22.040(1); 20 CSR 4240-22.040(2); 20 CSR 4240-22.040(4)(A)
[3] https://cdn.misoenergy.org/GIQ%20Web%20Overview272899.pdf

information gathered through Ameren Missouri's subject matter experts for use in the 2023 IRP can be found in Chapter 6 – Appendix A.

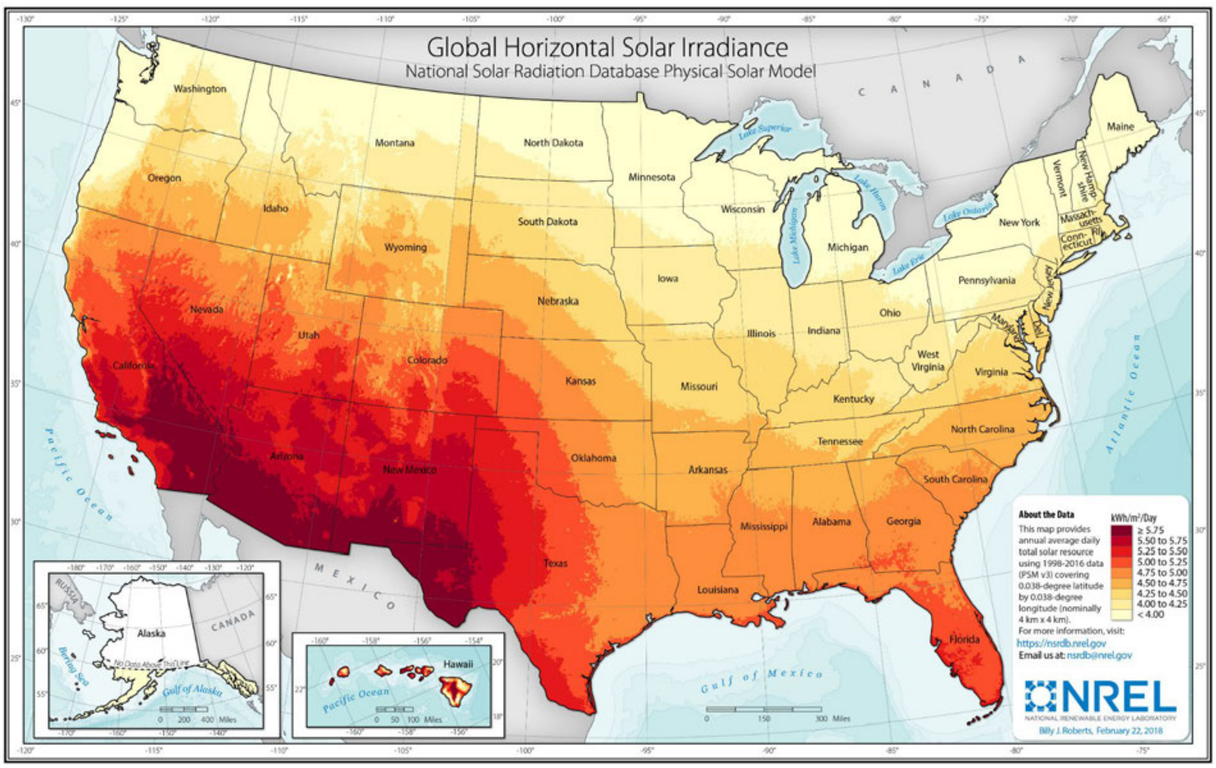
6.1.1 Potential Solar Resources

Based on a review of available solar technologies and Ameren Missouri's service territory, flat-plate solar photovoltaic (PV) is among the most practical, common, and cost-effective technologies for implementation.

Solar Resource & Technologies

The solar resource has three primary components: direct, diffuse, and ground reflected solar irradiances. Global Horizontal Irradiance (GHI) is the sum of all irradiances observed by a flat-plate over time. A map of the GHI for the U.S. is shown in Figure 6.2.

Figure 6.2 U.S. Global Horizontal Irradiance Map



As illustrated in the figure above, Missouri has a reasonably strong solar resource. St. Louis specifically averages an annual GHI value of 4.36 kWh/m^2-day.[4]

Concentrating solar power (CSP) technologies convert direct normal irradiance (DNI) into thermal energy to generate electricity via steam-turbine or engine. While the desert southwest has the highest DNI, there is ample GHI across much of the U.S. Solar PV technologies convert GHI into electricity via the photovoltaic effect. Both flat-plate PV and concentrating photovoltaic (CPV) collectors can be used to generate solar energy. Flat-

[4] NSRDB Physical Solar Model (PSM); St. Louis; TMY hourly data; GHI

plate collectors may be monofacial or bifacial, meaning light is collected on the top and bottom of the module. Due to the low cost of silicon-based materials and ample GHI resource across the U.S, bifacial flat-plate PV is the most practical and cost-effective solar technology.

Flat Plate Photovoltaics

PV capacity has grown to be the most common form of solar technology in the U.S., and Ameren Missouri expects it will remain the dominant solar technology option for deployment for the foreseeable future. As of March 2023, Wood Mackenzie reported there were nearly 90 GW of PV operating in the U.S. and 125 GW in the contracted pipeline. Of the utility-scale solar contracts signed in 2020, only 4% were under a mandated renewable portfolio standard, while more than 80% of projects were signed under voluntary procurement by a utility or corporate off-taker.[5] This is evidence of the continued improvement in technology and implementation techniques including:

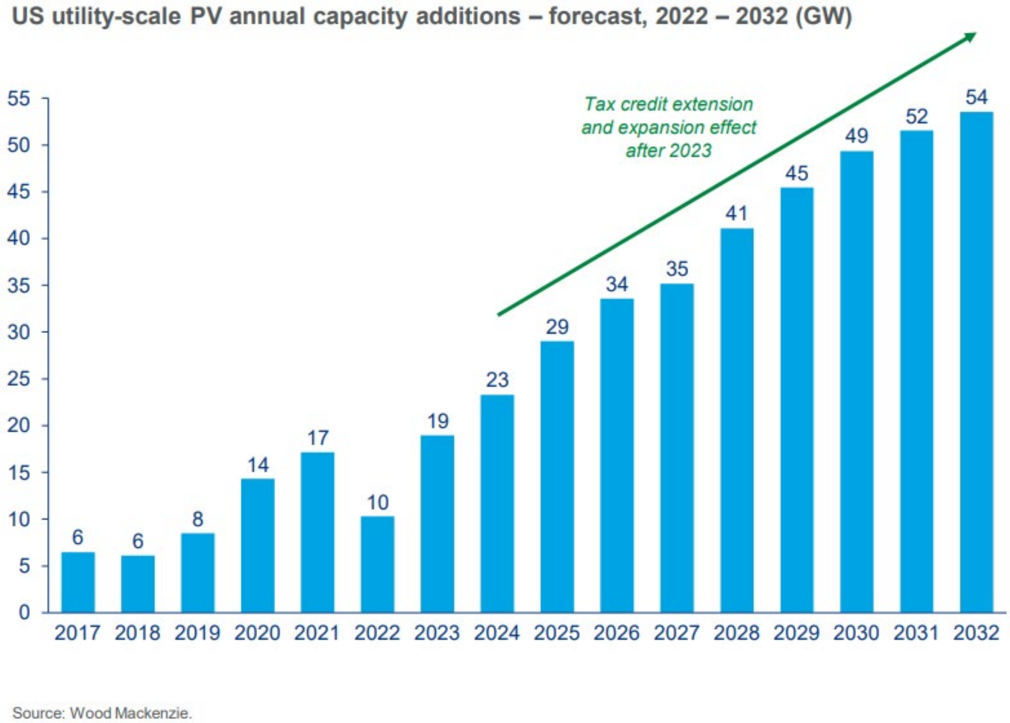
- Adoption of glass-on-glass bifacial modules that decreases degradation and extends its useful life
- Widespread use of single-axis trackers that yields higher capacity factors along with extended energy production windows
- Increase of solar module to inverter (DC:AC) ratios to further increase capacity factor

In the coming years, PV will continue to realize tax credit benefits thanks to the IRA. The IRA returned the Investment Tax Credit (ITC) to 30% of qualified costs and enabled PV to take advantage of the Production Tax Credit (PTC), which has historically been limited to wind projects. These full credits are contingent upon the project meeting prevailing wage and apprenticeship requirements. The law also enables projects to qualify for bonus tax credit adders including a domestic content adder (10% bonus) that applies to projects utilizing a defined amount of US manufactured materials, and an energy community adder (10% bonus) that applies to projects located in qualified areas such as brownfield, former fossil fuel sites, and those with lower employment rates.[6]

As discussed above, the IRA is expected to lead to increased PV capacity additions as depicted in Figure 6.3.

[5] Wood Mackenzie US Utility Scale Solar Market Update: Q4 2022, Page 14
[6] File No. EO-2023-0099 1.C

Figure 6.3 U.S. Utility-Scale PV Annual Capacity Additions – Forecast 2022-2032[7]



These capacity additions may further exacerbate supply chain challenges that have arisen due to the following:

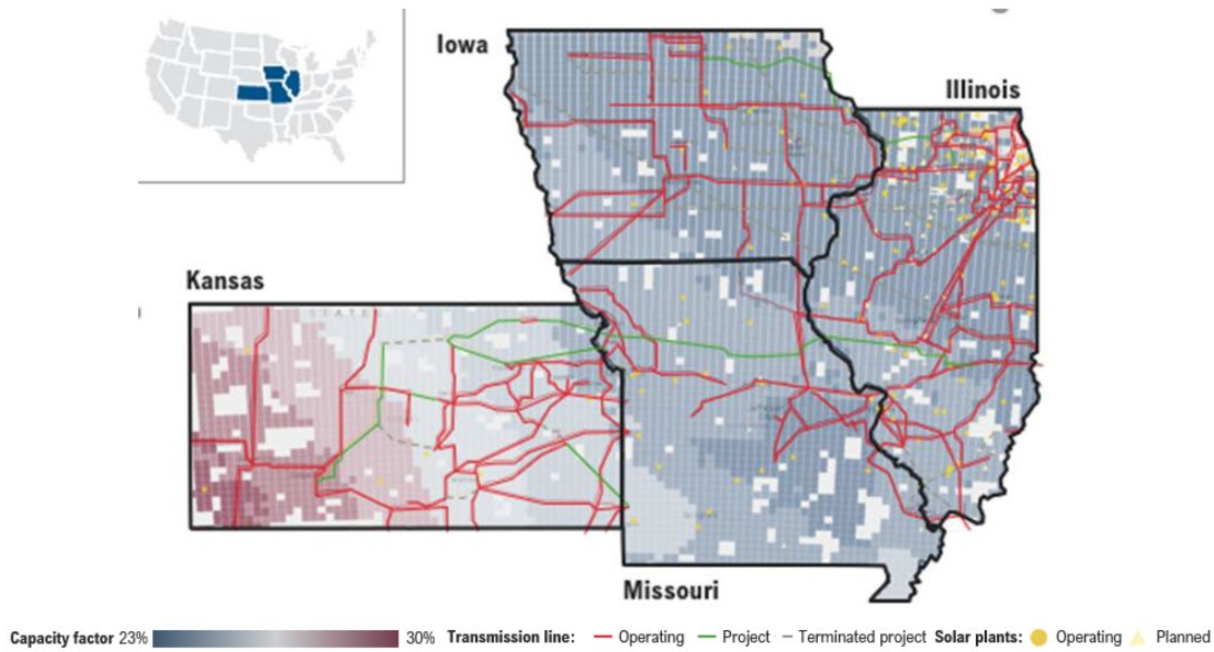
- Pandemic induced bottlenecks for key solar equipment in addition to increased containerized freight prices,
- U.S. Department of Commerce (DOC) anti-dumping and countervailing duties investigation in 2022, leading to potential significant punitive and retroactive tariffs on solar panels procured from Southeast Asia. An executive order signed by President Biden imposing a two-year moratorium on solar panel tariffs for solar projects completed by December 2024 has exponentially increased near term demand for solar panels,
- Passage of the Uyghur Forced Labor Prevention Act (UFLPA) banning imports of solar panels from China's Xinjiang region, leading to significant importation delays at U.S. customs,
- High U.S. inflation and a constrained construction labor market and increasing labor costs economy-wide.

Continued deployment of both PV and wind, discussed below, may be further constrained by the transmission system. More specifically, the high volume of MISO interconnection applications is leading to the need for additional transmission upgrades and to delays in receiving Generator Interconnection Agreements (GIAs). Interconnection queue reform remains critical for MISO as utilities across the ISO work to bring new resources online.

[7] Wood Mackenzie US Utility Scale Solar Market Update: Q4 2022, Page 6

Figure 6.4 overlays solar resource capacity factors, existing and planned projects, and existing and planned transmission lines in Ameren Missouri's region.

Figure 6.4 Map of Solar Capacity Factors, Development, and Transmission Lines[8]



Source: Roland Berger; NREL; S&P Global. Note: AC capacity factor.

The transmission system constraints coupled with balance of system savings may lead to repowering or extending the life of PV facilities. When repowering, the solar PV modules and inverters are replaced at or near end-of-life to maintain the power output of the facility. While the expected economic life of a utility-scale PV facility is 30 years in Missouri, developer land leases often extend out 35 years and beyond – an indication that the market is considering these strategies for the future. Ameren Missouri continues to evaluate how repowering strategies may provide value for customers.

Ameren Missouri Photovoltaics

In addition to the solar assets currently in operation in Ameren Missouri's generation fleet, the Company plans to build additional solar resources in the coming years. Two of those solar resources have received regulatory approval and are moving forward with construction: Huck Finn and Boomtown Renewable Energy Centers. Each planned solar resource addition is detailed below:

Huck Finn Renewable Energy Center

Huck Finn Renewable Energy Center is a 200 MW-AC solar energy center located in Audrain and Ralls County, Missouri. The resource received regulatory approval on

[8] Roland Berger Market Study: The Risk of Ameren Missouri Delaying Renewable Development; May 2022, pg. 24

February 8, 2023 and is currently under construction. It is expected to be commercially operational in late 2024 and will be utilized to support Ameren Missouri's compliance with the Missouri Renewable Energy Standard.

Boomtown Renewable Energy Center

Boomtown Renewable Energy Center is a 150 MW-AC solar energy center located in White County, Illinois. The resource received regulatory approval on April 12, 2023 and is currently under construction. It is expected to be commercially operational in late 2024 and will be utilized to support the Renewable Solutions Program.

Table 6.1 lists the primary characteristics of solar resources. Chapter 6 – Appendix A contains more detailed information.

Table 6.1 Forecasted Potential Solar Resources (2023$)

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Despite supply chain challenges, Ameren Missouri expects that on average the installed cost of solar will continue to decline in real terms, and therefore is using a declining curve informed by market data and the NREL 2022 Annual Technology Baseline (ATB) data, which is shown in Figure 6.5 below.

Figure 6.5 Base Solar Overnight Capital Cost Assumption (2023$)

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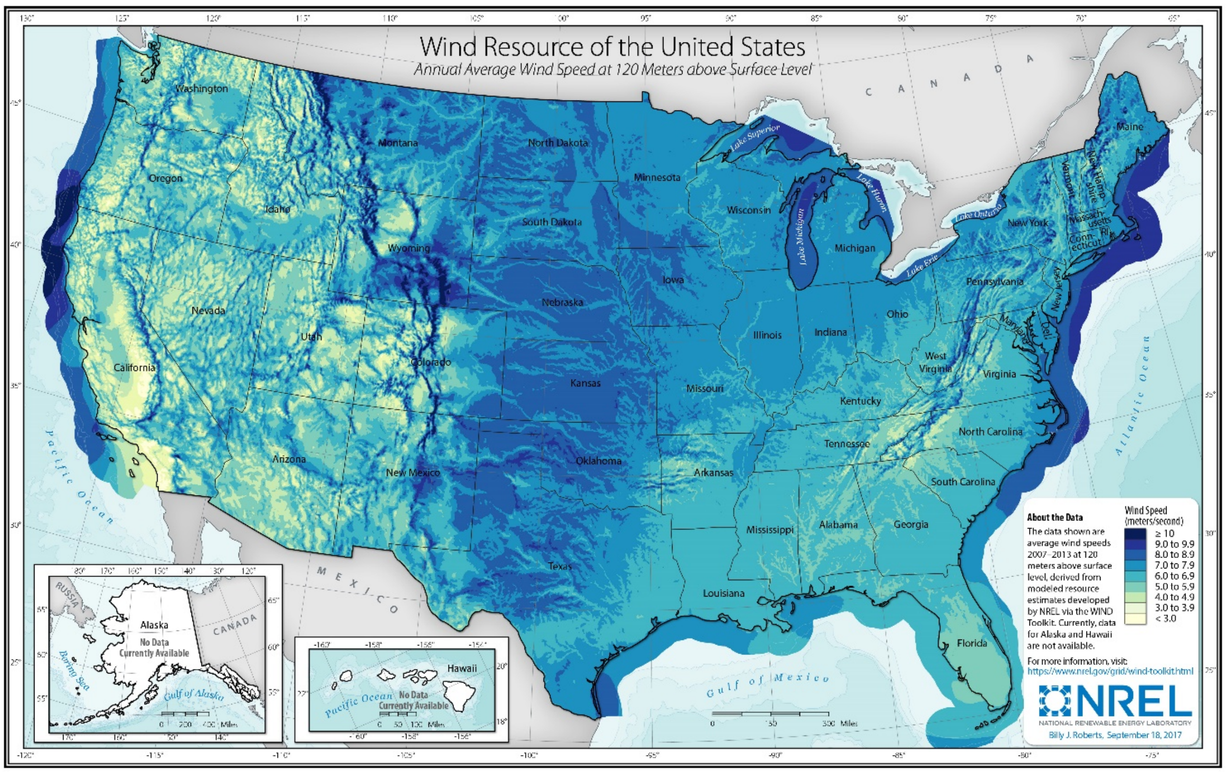
6.1.2 Potential Wind Resources

Wind Resource & Technologies

Historically, Missouri has seen limited deployment of wind generation compared to its western neighbor states. This is because the wind speed drops moving from west to east as one crosses the Kansas-Missouri border. Figure 6.6 below, which maps the average wind speed at 120 meters above surface level illustrates this fact.

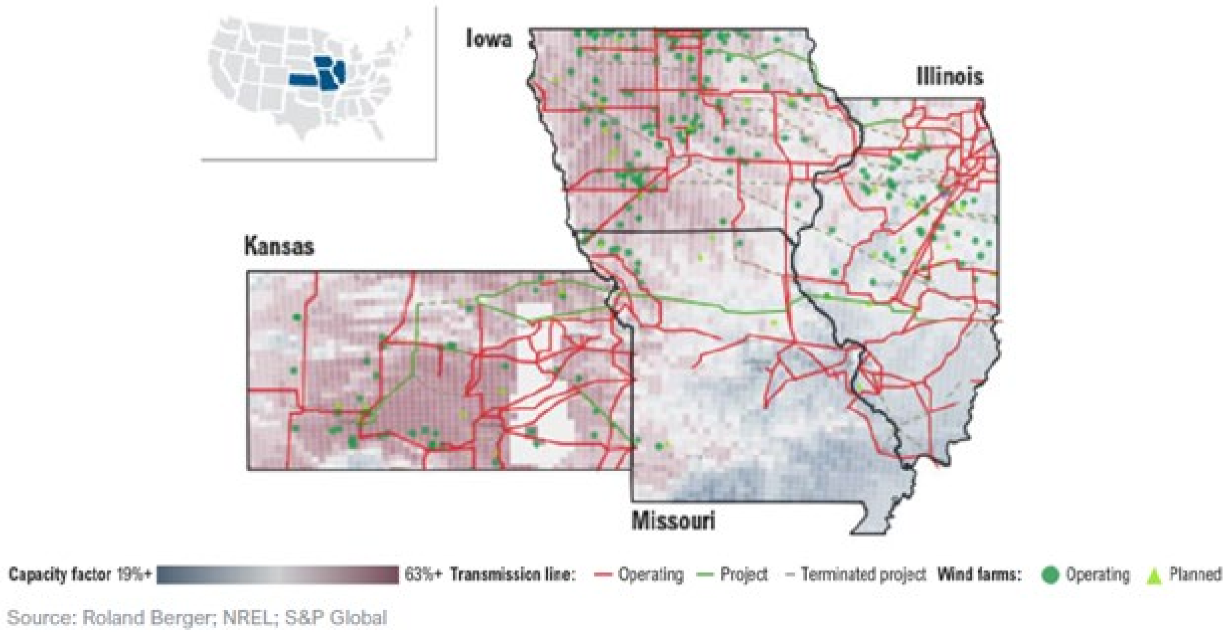
Figure 6.6 U.S. Wind Resource Map – 120 m above surface level[9]



The lower wind resource has translated into fewer wind projects as illustrated in Figure 6.7 below.

[9] https://www.nrel.gov/gis/assets/images/wtk-120m-2017-01.jpg

Figure 6.7 Map of Wind Capacity Factors, Development, and Transmission lines[10]

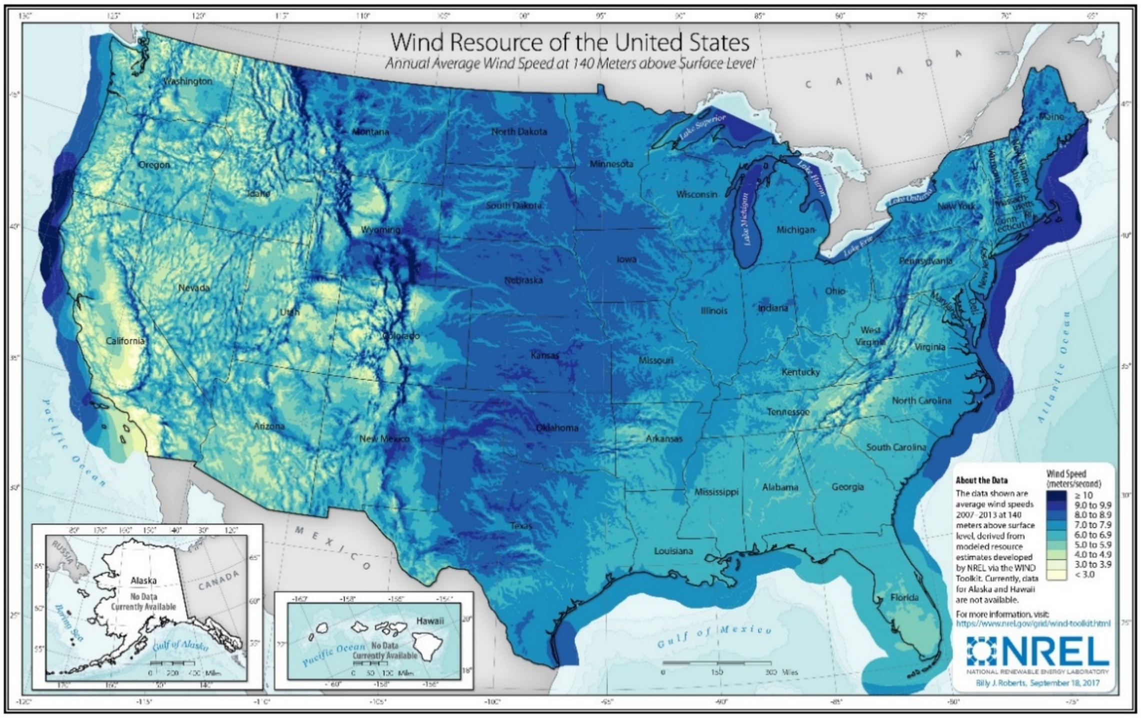


However, with the advent of new technologies, modern turbines are getting bigger and can be mounted on higher masts. The height for turbine "hub," the part of the turbine that houses the nacelle, generator, and other ancillary systems has been increasing, with the most recent turbine models at hub heights of 140 meters or more.[11]

The NREL map below, Figure 6.8 shows the wind speed at 140 meter above the surface level.

[10] Roland Berger Market Study: The Risk of Ameren Missouri Delaying Renewable Development; May 2022, pg. 12
[11] https://www.vestas.com/en/products/enventus-platform/v150-6-0

Figure 6.8 U.S. Wind Resource Map – 140 m above surface level[12]



As the map shows, Missouri has considerably more regions of good wind resource (shown in dark blue colors) at the 140-meter height, which may improve future wind generation opportunities in the state.

Ameren Missouri Wind

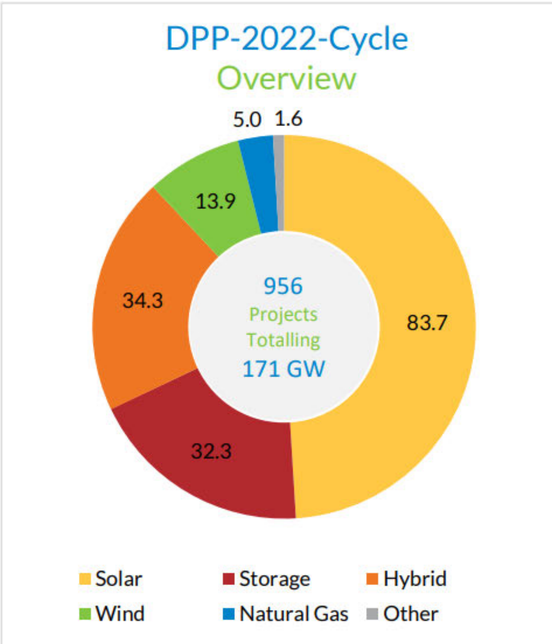
Ameren Missouri currently has two wind facilities in its generation fleet as discussed in Chapter 4: the Atchison Renewable Energy Center, and the High Prairie Renewable Energy Center.

Ameren is evaluating the wind (and solar) projects submitted in response to its request for proposals (RFP) in 2022 and may bring a wind project forward after completing preliminary diligence. In the near-term, wind project opportunities in Ameren Missouri's region appear more limited than solar project opportunities. Lower wind resource, longer wind development timelines, and (until the recent passage of the IRA) declining PTC values combined have likely been driving the relatively slow wind deployment in the region.

[12] https://www.nrel.gov/gis/assets/images/wtk-140m-2017-01.jpg

However, the continued technology evolution for wind together with the recently extended tax credits in the IRA has helped increase interest in wind development in the region, as demonstrated in the MISO GIA queue statistics shown in Figure 6.9.

Figure 6.9 MISO 2022 Generator Interconnection Queue Submissions[13]



Fuel	# of Requests	GW
Solar	469	83.7
Storage	231	32.3
Hybrid	163	34.3
Wind	66	13.9
Natural Gas	21	5.0
Other	6	1.6
Grand Total	**956**	**170.8**

FUEL	# OF REQUESTS	GW
Central	**301**	**54.5**
Solar	137	22.1
Storage	78	13.1
Hybrid	66	14.6
Wind	16	2.9
Natural Gas	4	1.8
East (ATC)	**30**	**4.0**
Solar	10	1.2
Storage	11	1.7
Hybrid	2	0.1
Wind	1	0.2
Natural Gas	6	1.0
East (ITC)	**89**	**14.9**
Solar	57	9.2
Storage	22	3.8
Hybrid	8	1.5
Natural Gas	2	0.3
South	**400**	**71.9**
Solar	222	44.5
Storage	83	7.2
Hybrid	79	15.8
Wind	10	2.6
Natural Gas	1	0.2
Other	5	1.6
West	**136**	**25.4**
Solar	43	6.8
Storage	37	6.5
Hybrid	8	2.2
Wind	39	8.2
Natural Gas	8	1.7
Other	1	0.0
Grand Total	**956**	**170.8**

As Figure 6.9 shows, there are around 5,500 MW of new wind project applications in the 2022 MISO queue for the MISO Central and the MISO South regions providing a reasonably robust medium-term pipeline of wind projects for Ameren Missouri.

[13] https://cdn.misoenergy.org/2022%20GIQ%20Submission%20Statistics626443.pdf

Accordingly, Ameren Missouri will continue to look for opportunities to evaluate and advance wind projects from this medium-term pipeline.

Lastly, Ameren will also be evaluating the potential for new wind (and other technologies) around its retiring generation station using the MISO generator replacement process or combining wind (or solar) with its existing combustion turbine generation facilities to leverage the transmission capacity.

Using market data for available regional wind projects as a reference point, Ameren Missouri subject matter experts revised the cost and operational characteristics of wind resources to be used in the 2023 IRP as can be seen in Table 6.2. Chapter 6 – Appendix A contains more detailed information.

Table 6.2 Forecasted Potential Wind Resources (2023$)

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Ameren Missouri expects that on average the installed cost of wind will continue to decline in real terms, and therefore, is using a declining curve informed by market data and the NREL 2022 Annual Technology Baseline (ATB) data as shown in Figure 6.10.

Figure 6.10 Base Wind Overnight Capital Cost Assumption (2023$)

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6.1.3 Potential Storage Resources[14]

Ameren Missouri has considered a range of storage resource options, including pumped hydro storage, CAES, stacked blocks (gravity storage), liquid air, and a number of BESS technologies. A high-level fatal flaw analysis was conducted as part of the first stage of the supply-side selection analysis for storage resources. Options that did not pass the high-level fatal flaw analysis consist of those that could not be reasonably developed or implemented by Ameren Missouri. Two options passed the initial screen: pumped hydroelectric energy storage, and lithium-ion battery energy storage. Table 6.3 lists primary characteristics of storage resources. Chapter 6 – Appendix A contains detailed resource characteristics.

Pumped Hydroelectric Energy Storage

Pumped hydroelectric energy storage is a large-scale, mature, commercial utility-scale technology used at many locations in the United States and worldwide. Conventional pumped hydroelectric energy storage uses two water reservoirs, separated vertically. During lower priced hours (historically off-peak periods), water is pumped from the lower reservoir to the upper reservoir. During high priced periods, (typically on-peak hours), the water is released from the upper reservoir to generate electricity. Church Mountain, located about midway between Taum Sauk State Park and Johnson Shut-ins State Park, was identified as the potential site for a new 600 MW pumped hydro plant. Multiple design factors can materially impact the costs of a pumped storage facility, including geography, installed capacity, and storage time. Costs used in the 2020 IRP were escalated for inflation, adjusted for transmission interconnection cost, and were used for the LCOE calculation in Table 6.3 Potential Energy Storage Resources.

Battery Energy Storage Systems

Battery Energy Storage Systems have been deployed throughout the United States as both supply-side and demand-side resources. BESS can provide services such as frequency regulation, frequency response, load shifting, and renewable energy smoothing, to name a few. As more intermittent renewable generation is deployed within Ameren Missouri's service territory and the surrounding regions, BESS will become more valuable as a controllable grid resource.

Ameren Missouri continues to analyze different BESS chemistries.[15] Technologies such as sodium-sulfur, while mature, have limited capabilities when compared to emerging technologies, such as lithium-ion and redox flow batteries. Advanced lead-acid batteries

[14] 20 CSR 4240-22.040(1); 20 CSR 4240-22.040(2); 20 CSR 4240-22.040(4)(A); File No. EO-2023-0099 1.G
[15] 20 CSR 4240-22.040(2)(C)2

also continue to improve but face a challenging market with the continued pressure from lithium-ion battery products.

Lead Acid Batteries

Since 2015, Ameren Missouri has been supporting applied research and the actual piloting of this technology at the Missouri University of Science and Technology in Rolla, MO. Today, we are designing, procuring, and deploying this technology at a Managed Charging for Fleet EVs site for Ameren vehicles.

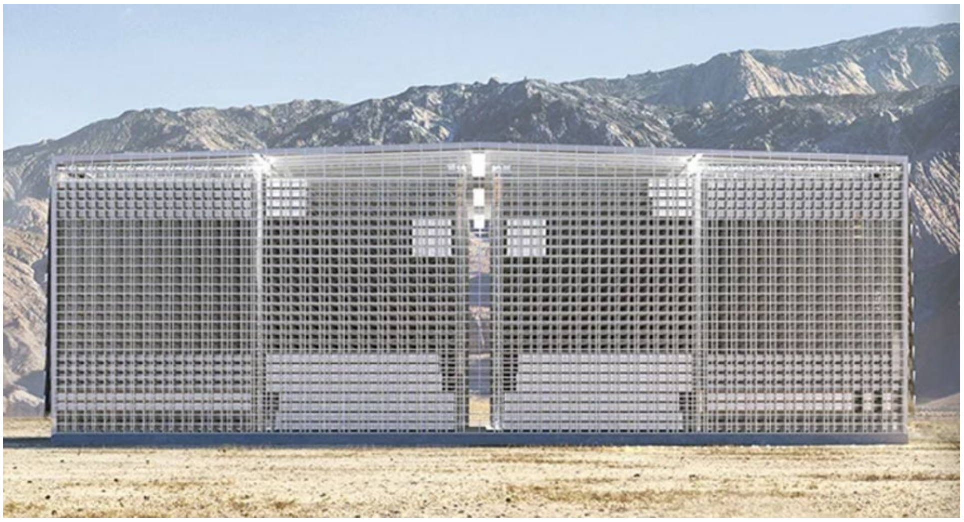
Ameren Missouri is committed to supporting our region's economic development by helping bring to market lead-acid battery products that are mined, processed, manufactured, marketed, and recycled in our state. Through the above-described demonstration project, we will evaluate the safety and techno-economic performance of lead-acid battery technology around the following use cases: resiliency, demand charge management, demand response, and optimum charger dispatch.

Some of the challenges Ameren Missouri has observed for advanced lead-acid batteries include lower energy density as compared to lithium-ion chemistries, larger footprint requirements for similar performance to lithium-ion applications, and performance and cyclic-life limitations. Lead-acid battery technology is very mature and has mature recycling opportunities to address overall performance, however, this application of energy storage has not demonstrated that it is a commercially viable and widely deployed technology for the reasons mentioned above.

Gravitational Energy Storage (GES)

Gravity-based energy storage system consists of thousands of stackable concrete composite blocks, trolleys, reversible hoist motor-generators, sensors and cameras, and control software. Potential energy is stored by lifting the blocks from ground-level to a higher position using the reversible direct-current (DC) hoist motor-generators in motor mode. Kinetic energy is released and converted to electricity when the blocks are returned to the ground by gravity, with the hoist motor-generators operating in generator mode. In essence, the process involves raising many large blocks to charge and subsequently lowering them to discharge. The velocity with which the blocks are lifted and lowered can be varied to control the rate of load absorption and power release, respectively.

Figure 6.11 Concrete Block Storage System – Blocks in a Large Modular Grid[16]



The leading company commercializing this technology is Energy Vault. They offer storage of energy for several hours using low-cost materials that can be locally sourced almost anywhere. Designed to be deployed in 10MWh blocks, the system can be configured for 2-18 hours of storage duration with a round-trip-efficiency of over 80%. A project rated at a nominal 25MW of power and 100MWh of energy started construction in May 2022 and will be completed in late 2023 in China.

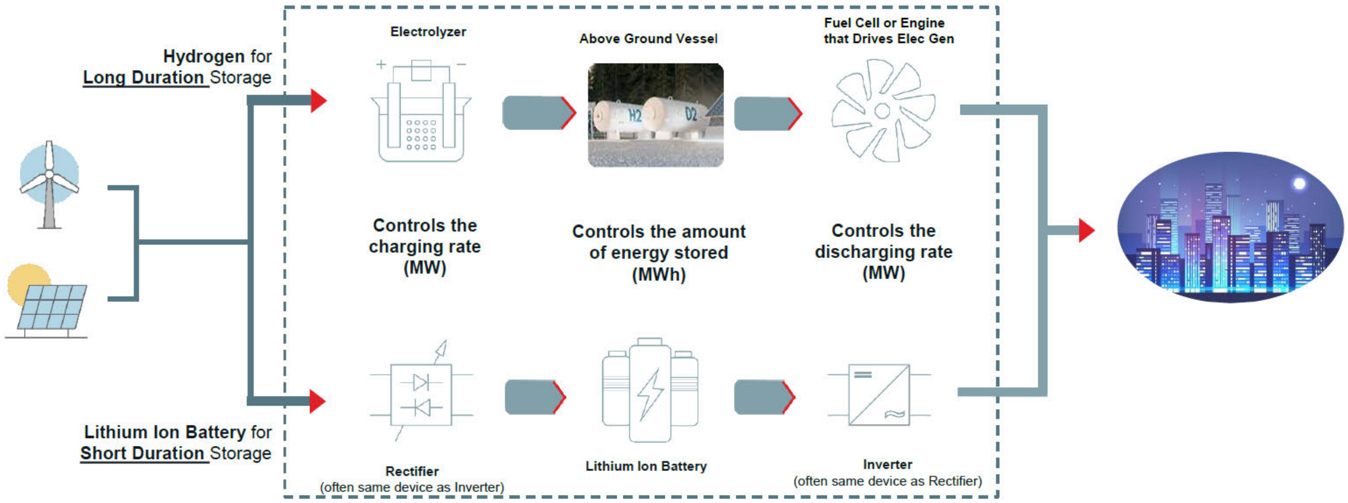
Another GES technology is Advanced Rail Energy Storage (ARES). ARES uses rail technology to harness the power of gravity. ARES' highly efficient electric motors drive mass cars uphill, converting electric power to mechanical potential energy. When needed, mass cars are deployed downhill delivering electric power to the grid quickly and efficiently. Currently, there is only one project under development in Pahrump, Nevada.[17]

Hydrogen Production & Storage

Hydrogen provides long-duration energy storage. Hydrogen can be stored and then consumed when needed by combustion in a combustion turbine, fuel cell, or industrial process. The amount of stored energy will depend on the size of tanks and other equipment. Ameren is investigating the potential application of hydrogen energy storage and planning demonstration projects.

[16] https://www.energyvault.com/ldes
[17] https://aresnorthamerica.com/

Figure 6.12 Equivalency Between Lithium Ion and Hydrogen Storage Systems[18]



Ameren has completed a feasibility study that considered a variety of loads: (1) transportation (hydrogen buses and tractor trailers); (2) blending (to feed into a load that can take natural gas and hydrogen); and (3) hydrogen fuel cell (for electrical loads as shown in the above illustration). The study concluded that it is technically feasible for hydrogen to address all of the above loads. However, commercially available system components have not yet been optimized for wide adoption.

Above Ground/Underground Compressed Air Energy Storage (CAES)

Deployed facilities are comparable to pumped-hydro power plants. In a CAES plant, rather than pumping water from a lower to a higher pond, ambient air is compressed and stored under pressure in an above-ground vessel or underground cavern. When electrical energy is needed, heated and expanded pressurized air is used to power a generator by an expansion turbine.

- Air heats up when compressed from atmospheric pressure to a storage pressure of approximately 1,015 psia (70 bar).
- Standard multistage air compressors use inter- and after-coolers to reduce discharge temperatures to 300/350°F and cavern injection air temperature to 110/120°F.
- The heat of compression therefore is extracted during the compression process or removed by an intermediate cooler.
- In the diabatic storage method, the loss of this heat energy must be compensated for during the expansion turbine power generation phase by heating the high-pressure air in combustors using natural gas fuel, or alternatively, using the heat of a combustion gas turbine exhaust in a recuperator to heat the incoming air before the expansion cycle.

[18] Mitsubishi Power Technical Sales Material

- In the adiabatic storage method, the heat of compression is thermally stored before entering the cavern and used for adiabatic expansion while extracting heat from the thermal storage system.

Large volume storage sites are required because of the low storage density. Underground and above-ground storage are viable options. For larger energy storage requirements, preferred locations include artificially constructed salt caverns in deep salt formations. Salt caverns are characterized by high flexibility, no pressure losses within the storage repository, and no reaction with the oxygen in the air and the salt host rock. If no suitable salt formations are present, it is also possible to use natural aquifers. However, tests must be carried out first to determine whether the oxygen reacts with the rock and with any microorganisms in the aquifer rock formation, which could lead to oxygen depletion or the blockage of the pore spaces in the reservoir. Depleted natural gas fields are also being investigated for compressed air storage; in addition to the depletion and blockage issues mentioned above, the mixing of residual hydrocarbons with compressed air will have to be considered.

Currently, there are only two CAES projects in operation – one in Alabama and the other in Germany.

Liquid Air Energy Storage (LAES)

A large-scale, long-duration energy storage technology that can be installed at the site of demand. Liquid nitrogen or liquefied air (~78% air) is the operating fluid. LAES systems can capture industrial low-grade waste heat/waste cold from co-located operations and exhibit performance traits similar to pumped hydro storage. The systems' size ranges from about 5MW to 100+ MWs, and since capacity and energy are uncoupled, they are ideal for long-term uses.

The LAES process utilizes parts and subsystems that are mature technologies that are readily accessible from significant OEMs, despite being novel at the system level. The technology extensively utilizes established power generation and industrial gas sector processes.

Three fundamental mechanisms comprise LAES:

Stage 1 - Getting the device charged: The charging device is an air liquefier, which draws air from the environment, cleans it, and then chills it to below-freezing temperatures until the air liquefies. One liter of liquid air is created from 700 liters of atmospheric air.

Stage 2 - Energy store: An insulated tank with low pressure is used as the energy storage, and liquid air is kept there. The use of this apparatus for the bulk storage of LNG, liquid nitrogen, and oxygen is already widespread. The industrial tanks that are used have the capacity to keep GWh of energy.

Stage 3 - Power Restoration: Liquid air is drawn from the tank(s) and pumped to high pressure when electricity is needed. The air is evaporated and superheated to ambient temperature. This produces a high-pressure gas, which is then used to drive a turbine.

In conclusion, LAES offers an output of hundreds of MWs, can be deployed at large-scale, and has an intrinsic capability for long-duration energy storage. To increase system efficiency, LAES systems can use industrial waste heat/cold from thermal generation facilities, steel mills, and LNG terminals. LAES makes use of proven components with established long lifespans (30 years or more), and performance.

Redox Flow Batteries (RFB)

They represent one class of electrochemical energy storage devices. The name “redox” refers to the chemical reduction and oxidation reactions employed in the RFB to store energy in liquid electrolyte solutions which flow through a battery of electrochemical cells during charge and discharge. The energy is stored in the volume of electrolyte, which can be in the range of kilowatt-hours to tens of megawatt-hours, depending on the size of the storage tanks. The power capability of the system is determined by the size of the stack of electrochemical cells. The amount of electrolyte flowing in the electrochemical stack at any moment is rarely more than a few percent of the total amount of electrolyte present (for energy ratings corresponding to discharge at rated power for two to eight hours). Flow can easily be stopped during a fault condition. As a result, system vulnerability to uncontrolled energy release in the case of RFBs is limited by system architecture to a few percent of the total energy stored. This feature is in contrast with packaged, integrated cell storage architectures (lead-acid, Li-Ion, etc.), where the full energy of the system is always connected and available for discharge.

RFBs are suited for applications with power requirements in the range of tens of kilowatts to tens of megawatts, and energy storage requirements in the range of 500 kilowatt-hours to hundreds of megawatt-hours.

Redox flow batteries have one main architectural disadvantage compared with integrated cell architectures of electrochemical storage. RFBs tend to have lower volumetric energy densities than integrated cell architectures, especially in the high power, short duration applications. This is due to the volume of electrolyte flow delivery and control components of the system, which is not used to store energy, so a system is not as compact as other technologies might be for a similar output.

Redox flow batteries show great promise with regard to cyclic life and performance but have not demonstrated commercial viability at the time of this IRP filing. Ameren Missouri continues to monitor and network with other utilities, such as San Diego Gas & Electric (SDG&E), as they operate their vanadium-redox flow battery at their Miguel Substation.

The SDG&E redox flow battery currently tests voltage, frequency and power outage support as well as shifting energy demand.

Lithium-ion Batteries

In addition to electric vehicle and backup systems for residential and commercial applications, lithium-ion (Li-ion) systems have emerged as the preferred choice for new grid-scale storage systems in the United States. Li-ion battery prices have fallen an average of more than 22% year-over-year since 2013.[19] Furthermore, just within MISO, the capacity of energy storage interconnection requests has increased dramatically from 140 MW in 2017 to 32 GW in 2022. Many of the MISO interconnection requests for energy storage are also paired with an intermittent renewable resource, such as solar.

Li-ion batteries have also been deployed in the PJM regional transmission organization and the New York Independent System Operator to provide frequency regulation. The California Independent System Operator (CA-ISO) demonstrates the need for energy storage to provide capacity and demand management. For background, California public utilities expect a capacity shortfall in Southern California and have responded to an order from the California Public Utilities Commission to meet this need. Furthermore, Tesla has received much notice for installing a 100-MW battery in Australia that provides grid stabilizing services.

Table 6.3 shows the energy storage technologies that were evaluated as candidate resource options. Lithium-ion battery energy storage was selected as an energy storage resource to be evaluated in the remaining resource planning process as a major supply-side resource in addition to pumped hydro storage. Ameren Missouri expects that on average the cost of batteries will continue to decline, and therefore has assumed a declining cost curve using Roland Berger and NREL data. Battery system offerings to customers were evaluated in the DSM Market Potential Study and were not found cost effective; therefore, only utility-owned storage systems were evaluated in the analyses discussed in Chapter 9.[20]

[19] *SEPA 2019 Utility Energy Storage Market Snapshot*
[20] File No. EO-2023-0099 1.G

Table 6.3 Potential Energy Storage Resources (2023$)

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Figure 6.13 Base Battery Overnight Capital Cost Assumption (2023$)

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6.1.4 Potential Hydroelectric Projects

Ameren Missouri previously performed studies to identify potential hydroelectric supply-side resources and projects; however, in this IRP, is using generic project characteristics from EIA and NREL. In addition to cost, several factors contribute to the feasibility of these projects, including accessibility of a water resource, environmental constraints, and regulatory definitions that define what types and sizes of hydropower are considered "renewable." For instance, the state of Missouri defines "renewable" hydropower in the Renewable Energy Standard (RES), which states hydropower generators can only be considered renewable energy sources if they meet the criteria, "hydropower (not including

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pumped storage) that does not require a new diversion or impoundment of water and that has a nameplate rating of 10 megawatts or less."

Table 6.4 contains details of a generic hydroelectric project. Hydro resource was evaluated assuming a 60-year economic life. Because the cost estimates are screening level estimates and because obtaining necessary licenses from the FERC can be complex, a more detailed evaluation of specific projects would be necessary before moving forward with a decision to construct.

Table 6.4 Potential Hydroelectric Resource

Resource Option	Plant Output (MW)	Project Cost with Owner's Cost, Excluding AFUDC ($/kW)	First Year Fixed O&M Cost ($/kW)	First Year Variable O&M Cost ($/MWh)	Assumed Annual Capacity Factor (%)	LCOE without Incentives (¢/kWh)
Hydro	50	$5,704	$99.0	$0.0	60%	19.61

6.1.5 Potential Landfill Gas Projects

Landfill gas (LFG) is produced by the decomposition of the organic portion of waste stored in landfills. LFG typically has methane content in the range of 45 to 55% and is considered an environmental issue. Methane is a potent greenhouse gas, 25 times more harmful than CO_2 by some estimates. In many landfills, a collection system has been installed, and the LFG is being flared rather than being released into the atmosphere. By adding power generation equipment to the collection system (reciprocating engines, small gas turbines, or other devices), LFG can be used to generate electricity. LFG energy recovery is currently regarded as one of the more mature and successful waste-to-energy technologies. There are currently nearly 532 operational LFG energy systems in the United States.[21]

Ameren Missouri continues to operate the Maryland Heights Renewable Energy Center (MHREC) at the IESI Landfill in Maryland Heights, Missouri. Previous studies have identified other landfills within the Ameren Missouri service territory that could support another LFG facility. At this time, however, other renewable resources are more abundant and more cost effective. Ameren Missouri will continue to monitor this technology for opportunities for future deployment.

[21] https://www.epa.gov/lmop/landfill-gas-energy-project-data-and-landfill-technical-data

6.1.6 Potential Biomass Projects

A study on potential biomass project feasibility had previously been conducted for Ameren Missouri. The study included identification of potential sites, technologies, resource locations, characteristics and availability, and costs. Several factors, including resource location and geographical constraints related to potential biomass projects, coupled with the cost structure and technology stagnation, especially in comparison to significant improvements in other renewable technologies, have reduced the focus on biomass as a new supply-side resource in this IRP.[22] Ameren Missouri will continue to monitor this resource potential for technological advancements and cost structure improvements. Any potential future project proposals will be evaluated as they materialize.

6.1.7 Innovative Renewables Deployment[23]

Ameren Missouri is exploring various methods to incorporate and deploy more renewable generation throughout its service territory. Among those methods are:

Community Solar: Ameren Missouri included an application for approval of a permanent Community Solar Program within the electric rate review filed in March 2021. The program features a variety of improvements to enhance the participation experience for customers. This proposal was approved as part of the electric rate review settlement agreement, and, as a result, the permanent Community Solar Program was rolled out to residential and small commercial customers in the latter half of 2022. The program redesign expands access and affordability by (1) lowering the program enrollment fee, (2) enabling customers to match up to 100% of their usage with solar energy, and (3) accelerating new facilities construction timelines.

Renewable Solutions: In 2022, Ameren Missouri filed for approval of a new subscription renewable energy program, the Renewable Solutions Program. Renewable Solutions is a voluntary renewable energy subscription program designed for larger commercial, industrial, and governmental customers. Many of Ameren Missouri's larger customers have publicly expressed their desire for near-term access to renewable energy in the form of sustainability goals for both carbon dioxide emission reduction and renewable energy supply. The program is designed to offer those customers a pathway to meet their sustainability goals with local renewable energy while reducing cost and risk for all Ameren Missouri customers. The Renewable Solutions Program was approved on April 12, 2023 and the first phase of the program, which will be supported by the Boomtown Renewable Energy Center, is fully subscribed.

[22] 20 CSR 4240-22.040(2)(C)2
[23] File No. EO-2023-0099 1.E

6.2 New Thermal Resources

6.2.1 Potential Natural Gas Options

The 2020 IRP included discussion of multiple natural gas supply-side resource options, addressing base, intermediate, and peaking load requirements.

Ameren Missouri previously studied combined cycle technology, including the evaluation of potential combined cycle generating configurations, and potential facility locations. Any future investment will require an updated evaluation to consider the latest technologies, costs, and developments that may impact a new energy center location. For example, since our last IRP, a new 24-inch natural gas pipeline has been constructed, bringing gas from the Rockies Express Pipeline in Illinois into Missouri, through St. Charles and north St. Louis counties. Multiple combined cycle configurations are possible, providing the opportunity and flexibility to tailor a supply-side resource solution to future requirements and constraints in a cost-effective manner. In this IRP, Ameren Missouri also included combined cycle with 98.5% carbon capture as a potential resource.

Table 6.5 contains details of potential natural gas projects. These projects were evaluated assuming a 30-year economic life. Because the cost estimates for these resources are screening level estimates developed from EIA, NREL, EPRI and Roland Berger data, a more detailed scope and evaluation of specific projects would be necessary before moving forward with a decision to construct.

Table 6.5 Potential Natural Gas Resources (2023$)

Resource Option	Plant Output (MW)	Project Cost with Owners Cost, Excluding AFUDC ($/kW-AC)	First Year Fixed O&M Cost ($/kW-year)	First Year Variable O&M Cost ($/MWh)	Assumed Annual Capacity Factor (%)	LCOE without Incentives (¢/kWh)
Greenfield Combined Cycle	1,200	$1,220	$62.0	$2.7	40%-80%	9.8 - 6.77
Greenfield Combined Cycle with CCS	1,135	$2,207	$106.5	$8.4	40%-80%	15.01 - 9.63
Simple Cycle	1,150	$994	$8.1	$5.2	5%	33.02

Project costs in the table include transmission interconnection costs as discussed in Chapter 7, and these costs may be avoided if they are constructed at retired coal energy center sites. It should also be noted that fixed O&M costs for both CC options include firm gas costs. The CC with CCS option also include additional capex and O&M for transportation and storage of captured CO_2 assuming a 100-mile pipeline is needed for transportation. Details can be seen in Table 6.6.

Table 6.6 Carbon Transportation and Storage Cost Assumptions (2023$)

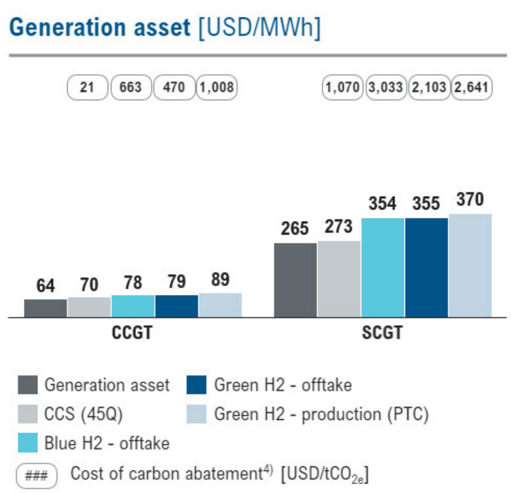
Sequestration Costs	Transportation			Storage	
	Capex ($/mile)	Pipe O&M (% of Capex)	Pump and Other O&M (% of Capex)	Storage Capex ($/ton)	Storage O&M ($/ton)
Transport and Store	750,994	2.3%	4.5%	$5.39	$4.84

Other thermal technologies remain as potential candidates for new supply-side resources, including reciprocating engines. Ameren Missouri will continue to monitor these arenas for technological advancement and cost structure improvements.

Hydrogen[24]

The IRA includes incentives for the production of green hydrogen in the form of production tax credits. Ameren Missouri has evaluated the economics of carbon emission abatement with the help of Roland Berger. The analysis reflects blending hydrogen with natural gas at a rate of 20 percent hydrogen (by volume). This analysis was performed under both an offtake agreement structure and ownership and operation of electrolyzers by Ameren Missouri. The analysis was performed for both CC and SC gas units and compared to the cost of abatement for CCS. The results of the analysis are shown in Figure 6.14 below. Based on these results, Ameren Missouri expects that hydrogen could play a limited role in abatement of carbon emissions from gas generation if hydrogen production for industrial uses can also produce economic green hydrogen for electric generation as an ancillary benefit. It should be noted that hydrogen production in the region is still expected to provide economic benefits by supporting industrial decarbonization for applications that are more difficult to electrify even if hydrogen is not used as a fuel for electric generation.

Figure 6.14 Comparative Economics of Hydrogen Fuel



[24] File No. EO-2023-0099 1.C

6.2.2 Potential Nuclear Resources

Consistent with Ameren Missouri's previous IRP filings, new nuclear was considered in this IRP for carbon-neutral around-the-clock generating capabilities. Ameren Missouri evaluated a conventional nuclear resource and a small modular reactor (SMR). Details are shown in Table 6.7.

Table 6.7 Potential Nuclear Resources

Resource Option	Plant Output (MW)	Total Project Cost Including Owners Cost, Excluding AFUDC ($/kW)	Annual Decommissioning Costs ($1,000)	First Year Fixed O&M Cost ($/kW-year)	First Year Variable O&M Cost ($/MWh)	Assumed Annual Capacity Factor (%)	LCOE (¢/kWh)
SMR	864	$8,492	$13,448	$122.1	$3.86	95%	15.81
AP1000	1,100	$10,109	$17,931	$151	$3.64	94%	19.60

SMRs have a number of characteristics that illustrate the unique role that they can play in our future energy mix: (1) SMRs are relatively small in power output versus large-scale reactors that can have a power output of more than 1,000 MWe; and (2) SMR designs are modular. Unlike traditional reactors, SMRs would be manufactured and assembled at a factory and shipped to the construction site as nearly complete units, resulting in much lower capital costs and much shorter construction schedules. SMRs also permit greater flexibility through smaller, incremental additions to baseload electrical generation, and more SMRs can be added and linked together for additional output as needed.

NuScale Power's SMR received the U.S. Nuclear Regulatory Commission's design certification in January 2023.[25] The NuScale Power Module is a 77 MWe advanced light-water SMR. Each power plant can house up to 12 modules, which will be factory-built and about a third of the size of a large-scale reactor. Its unique design allows the reactor to passively cool itself without any need for additional water, power or even operator action.[26]

DOE is supporting the siting of the nation's first SMR plant at Idaho National Laboratory. First module is expected to begin operating in 2029, with the remaining modules expected to come online by 2030.

6.3 Power Purchase Agreements

After discussions with Ameren Missouri's Asset Management and Trading organization it was determined that there were no pending potential long-term power purchases for

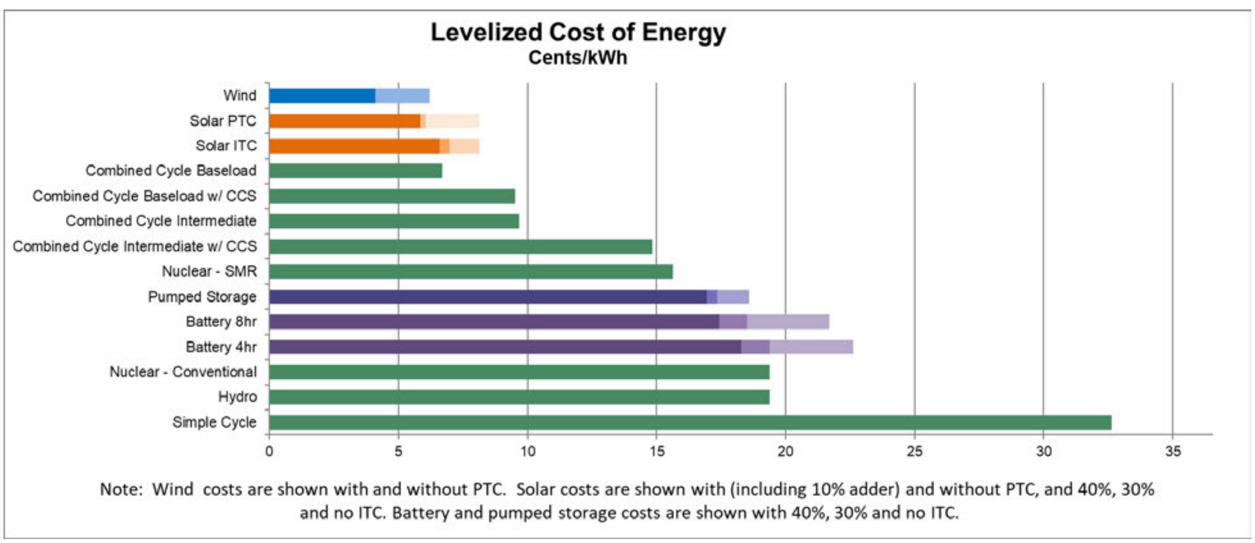
[25] https://www.federalregister.gov/documents/2023/01/19/2023-00729/nuscale-small-modular-reactor-design-certification
[26] https://www.energy.gov/ne/articles/nrc-approves-first-us-small-modular-reactor-design

consideration at the time of the analysis. Furthermore, Ameren Missouri learned from its experience in developing the 2008 and 2011 IRPs that soliciting the market for long-term power purchases or sales is not productive for bidders given the data at this stage of the analysis is generic, and potential respondents are reluctant to share information on potential agreements without a reasonable expectation for an executed contract. Evaluation of generic power purchase agreements would not be expected to yield different results in terms of relative performance of resource types, as the only reasonable assumption that could be made absent specific information would be that such an agreement would be effectively cost-based.

6.4 Final Candidate Resource Options[27]

Figure 6.15 demonstrates the LCOE with incentives (e.g., investment tax credits or production tax credits, if applicable) for a range of potential supply side resources. It is important to note that levelized cost of energy figures, while useful for convenient comparisons of resource alternatives, do not fully capture all of the relative strengths of each resource type. For example, wind resources are intermittent resources and therefore cannot be counted on for meeting peak demand requirements in the same way a nuclear or gas-fired resource can. Similarly, using an energy cost measure to evaluate peaking resources such as simple cycle combustion turbine generators (CTGs) does not fully reflect their value as a capacity resource or their quick-start capability. Table 6.8 shows the component analysis for the levelized cost of energy figures.

Figure 6.15 Levelized Cost of Energy



[27] 20 CSR 4240-22.040(4); 20 CSR 4240-22.040(4)(C)

Table 6.8 Levelized Cost of Energy Component Analysis[28]

Potential Resource	Levelized Cost of Energy (¢/kWh)								
	Capital	Fixed O&M	Variable O&M	Fuel	Resource Specific Cost	CO_2	SO_2	NO_X	Total Cost
Wind[1]	5.03	1.26	0.00	--	-2.13	--	--	--	**4.16**
Solar[1]	7.42	0.80	--	--	-2.09	--	--	--	**6.14**
Solar[2]	6.27	0.80	--	--	--	--	--	--	**7.07**
Combined Cycle: Greenfield	1.90	1.13	0.34	2.73	--	0.65	0.00	0.02	**6.77**
Combined Cycle w/ CCS: Greenfield[3]	3.44	1.85	0.51	3.17	0.62	0.01	0.00	0.02	**9.63**
Nuclear: SMR[4]	11.17	1.95	0.51	1.99	0.19	--	--	--	**15.81**
Nuclear: AP1000[4]	15.07	2.44	0.48	1.42	0.20	--	--	--	**19.60**
Hydro	15.64	3.97	0.00	--	--	--	--	--	**19.61**
Storage: Pumped Hydro[2,5]	10.75	0.27	0.48	--	6.05	--	--	--	**17.56**
Storage: Li-Ion Battery (8h)[2,5]	11.99	1.98	0.00	--	4.76	--	--	--	**18.73**
Storage: Li-Ion Battery (4h)[2,5]	12.21	2.64	0.00	--	4.76	--	--	--	**19.61**
Simple Cycle: Greenfield	24.44	2.37	0.66	4.40	--	1.05	0.00	0.10	**33.02**

1. Resource Specific Cost: Full PTC
2. 30% ITC
3. Resource Specific Cost : Carbon dioxide transportation and storage cost
4. Resource Specific Cost: Decommissioning fund
5. Resource Specific Cost : Battery charging/pump cost

The LCOE for future resource options is an important measure for assessing these options. However, it is not the only factor that must be considered in making resource decisions. Facts and conditions surrounding future environmental regulations, commodity market prices, economic conditions, economic development opportunities, and other factors must be considered as well. A robust range of uncertainty exists for many of these factors, all of which leads to one overriding conclusion – maintaining effective options to pursue alternative resources in a timely fashion is a prudent course of action.

28 20 CSR 4240-22.040(2)(B); 20 CSR 4240-22.040(2)(C)1

6.5 Compliance References