ENERGY SUPPLY

Energy Supply Reference Card

2023 Version

3002027620

Introduction

Every electricity generation technology has advantages and disadvantages. For example, renewable technologies such as solar and wind do not produce greenhouse gases but are not always available when needed and can require significant amounts of land. On the other hand, technologies such as coal and nuclear can produce electricity in large quantities reliably around the clock but can result in significant greenhouse gases when unabated (in the case of coal) or long-term waste disposal considerations (in the case of nuclear).

Understanding these tradeoffs among generating technologies reinforces the importance of having a diverse generation technology portfolio for reducing greenhouse gas emissions while economically and reliably meeting electricity demand. When applied as part of an integrated portfolio, all generation technologies can play useful roles that capitalize on their strengths.

This Energy Supply Reference Card explores some of the Advantages and Challenges of both current and emerging electricity generation technologies when comparing attributes including cost, availability and operational capabilities, and environmental considerations. It presents a comparison of technologies at a high level, followed by a more detailed explanation for the assessment of each parameter analyzed for each technology. While the assessments represent the general characteristics of the technologies evaluated, the exact details of many parameters will be unique to the site, region, and/or country in which the technology is being considered. Furthermore, the details around the costs and capabilities of emerging technologies are less certain than those of generation technologies that have been mature and commercialized for decades and reflect expectations more than demonstrated capabilities. While the information included here can help to inform the planning and stakeholder engagement processes, more detailed analyses are required for making final investment and deployment decisions.

Assessment of Relative Benefits and Impacts

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Advantage ⟵⟶ **Challenge**

	Coal	Coal + CCS	Natural Gas	NG + CCS	Biomass	Biomass + CCS	Nuclear	Small Modular Reactor (SMR) Nuclear	Hydro	Onshore Wind	Offshore Wind	Solar PV	Solar PV + Storage	Concentrating Solar Power (CSP)	Geothermal	Enhanced Geothermal Systems (EGS)
Construction Cost	◕	◔	●	◑	◑	◔	○	○	◔	●	◑	●	◕	◔	◔	○
Electricity Cost	◕	◔	●	◑	◔	○	◑	◑	◕	●	◑	●	◕	◑	◕	○
Capacity Factor	◕	◕	◕	◕	◕	◕	●	●	◑	◑	◑	◔	◑	◑	◕	◕
Ramping Capability	◑	◑	●	◕	◑	◑	◑	◑	●	◔	◔	◔	◕	◑	◕	◕
Availability	●	●	●	●	●	●	●	●	◕	○	○	○	◑	◑	●	●
Total Area Use Intensity	◑	◑	●	●	○	○	●	●	◑	◔	◔	◑	◑	◑	◕	◕
Direct Water Use Intensity	○	○	◕	◑	○	○	○	○	◑	●	●	●	●	◑	◕	◑
Direct Greenhouse Gas (GHG) Emissions	○	◕	◑	◕	◕	●	●	●	●	●	●	●	●	●	●	●
Other Direct Air Emissions	○	○	◑	◑	◔	◔	●	●	●	●	●	●	●	●	◕	◕
Direct Waste Products	○	○	●	◕	◑	◑	◔	◔	●	●	●	●	●	●	◕	◕
Ease of Permitting	○	○	◑	○	◑	○	○	◔	○	◕	◑	●	●	◕	◕	◕
End of Life Considerations	◑	◔	◕	◑	◑	◔	○	○	◑	●	◕	◕	◕	◕	◕	◕

Current Generation Technologies

	Coal	Natural Gas	Biomass	Nuclear	Hydro	Onshore Wind	Solar PV	Concentrating Solar Power (CSP)	Geothermal
Construction Cost	◕	●	◑	○	◔	●	●	◔	◔
Electricity Cost	◕	●	◔	◑	◕	●	●	◑	◕
Capacity Factor	◕	◕	◕	●	◑	◑	◔	◑	◕
Ramping Capability	◑	●	◑	◑	●	◔	◔	◑	◕
Availability	●	●	●	●	◕	○	○	◑	●
Total Area Use Intensity	◑	●	○	●	◑	◔	◑	◑	◕
Direct Water Use Intensity	○	◕	○	○	◑	●	●	◑	◕
Direct Greenhouse Gas (GHG) Emissions	○	◑	◕	●	●	●	●	●	●
Other Direct Air Emissions	○	◑	◔	●	●	●	●	●	◕
Direct Waste Products	○	●	◑	◔	●	●	●	●	◕
Ease of Permitting	○	◑	◑	○	○	◕	●	◕	◕
End of Life Considerations	◑	◕	◑	○	◑	●	◕	◕	◕

● **Advantage**
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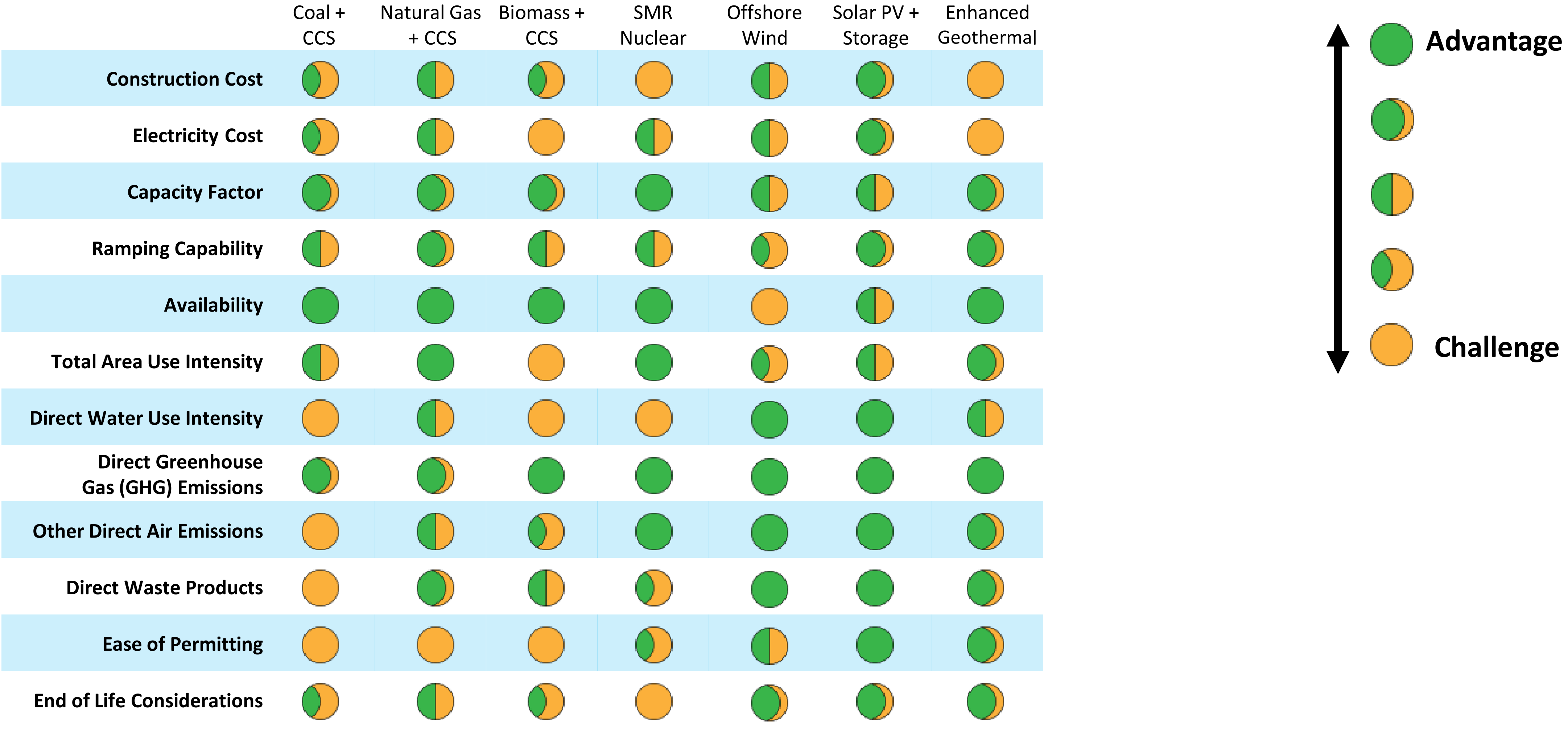
○ **Challenge**

EPRI

Emerging Generation Technologies

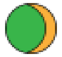
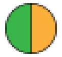
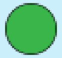
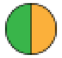
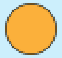
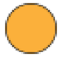
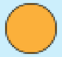
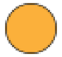
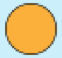
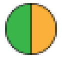


Details around the costs and capabilities of emerging technologies are less certain than those of generation technologies that have been mature and commercialized for decades. This assessment reflects expectations more than demonstrated capabilities.

Parameter	Definition
Construction Cost	The cost of constructing a new plant per unit of generating capacity. Includes costs of materials, equipment and labor for constructing the plant, contingency factors, engineering fees, owner's costs and financing charges during construction. Construction costs are less certain for emerging technologies that will have first-of-a-kind costs with expectations of cost decreases with increased deployment.
Electricity Cost	The cost to produce electricity from a new plant over its lifetime, based on new plant construction costs, operation and maintenance costs, fuel costs, and expected annual electricity production. No CO_2 policy is assumed, and CO_2-related costs and incentives are not included in the comparison.
Capacity Factor	The total amount of energy a plant produces during a period of time divided by the amount of energy the plant would have produced at full capacity.
Ramping Capability	The ability to increase or decrease output in response to changes in demand, plant scheduling, or output of other system resources to maintain reliability and compliance with applicable system standards. Rampling capability for emerging technologies reflect expectations but may not have demonstrated capabilities due to a lack of deployment to date.
Availability	The ability to generate electricity when needed, accounting for dispatchability and considering impacts of daily and seasonal variation in resource availability.
Total Area Use Intensity	The total land use per unit of generating capacity, but not considering capacity factor/amount of electricity generated. Total land use accounts for the total above surface plant boundary and fuel requirement but does not consider sub-surface operations. Dual use opportunities are also not considered.
Direct Water Use Intensity	The amount of water consumed by a plant per unit of electricity generated, reflecting the operational footprint only. Water requirements can vary significantly within a plant type based on cooling system type, local climate, water source, environmental regulations, and water management choices. This comparison assumes the same type of cooling system (close cycle, wet cooling) for all thermal plant types. Hydroelectric and geothermal water requirements are assessed on other factors.
Direct Greenhouse Gas (GHG) Emissions	The amount of GHGs emitted per unit of electricity generated. Reflects the emissions of GHGs produced by the plant in CO_2-equivalent and does not include lifecycle emissions.
Other Direct Air Emissions	The amount of non-GHG air emissions per unit of electricity generated, including nitrogen oxide (NOx), sulfur compounds (SOx), particulate matter, and hazardous air pollutants like mercury.
Direct Waste Products	The amount and/or impact of waste produced by power plant operations. Does not include waste produced by plant construction or decommissioning, or wastes associated with fuel extraction or transport.
Ease of Permitting	The readiness at a regional level for a type of generation, generally represented by the estimated time to receive a permit. This is a somewhat subjective measure that varies among regions.
End of Life Considerations	The ease or complexity of decommissioning a plant at end-of-life. Considers resource requirements to remediate the plant site for future use, long-term monitoring needs post-decommissioning, and disposal/recyclability of plant equipment.

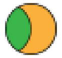
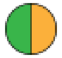
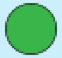
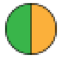
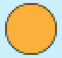
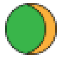
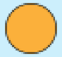
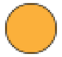
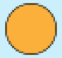
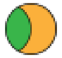
Coal

Includes pulverized coal (PC) technologies

Parameter	Rating	Reasoning
Construction Cost		Construction costs for new coal plants are relatively low when CCS is not included.
Electricity Cost		Electricity production costs for new coal plants are relatively low over their projected lifetimes because of the low, stable cost of coal and the large number of hours that a coal plant typically operates.
Capacity Factor		Coal plants can have high capacity factors. Actual operations depend on competitiveness with natural gas prices and other generation sources.
Ramping Capability		Coal plants operate most efficiently at full power. There is some ability to operate at reduced power output, but this is restricted based on requirements for environmental control operation. Following an outage, several hours are required for preheating the boiler before full operation can begin.
Availability		Coal plants are extremely reliable sources of electricity. They typically operate around the clock, for months at a time. Maintenance outages are typically scheduled during low demand periods in the spring and fall.
Total Area Use Intensity		Coal plants have a relatively small plant footprint for the generating plant and its supporting facilities for a given capacity. However, the mining area required for coal is relatively large compared with other fuels, making the overall land use requirements moderate.
Direct Water Use Intensity		Coal power plants require large amounts of water for operations, mostly to cool the steam that powers the turbine-generators to generate electricity.
Direct Greenhouse Gas (GHG) Emissions		Coal has the highest carbon intensity of all fossil fuels. As a result, coal plants without CCS are the largest GHG emitters of all new generation technologies.
Other Direct Air Emissions		Coal plant emissions include NOx, SOx, mercury, and particulate matter. New coal plant air emissions are just a fraction of the average emissions from the existing fleet of coal plants but are still much higher than other generating technologies.
Direct Waste Products		Coal plants have large volumes of waste products resulting from power generation. These include solid waste, such as ash remaining after combustion, and wastewater from the steam cycle and environmental control systems. In some regions, ash is reused, which would reduce the volume of resulting waste products.
Ease of Permitting		Because coal plants release a significant amount of GHG emissions, a new plant may not be permitted without CCS and may have to undergo stringent reviews.
End of Life Considerations		Coal plants require resources to remediate the plant site and to continue monitoring the environmental impacts of coal combustion product storage units in locations that have them.

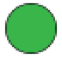
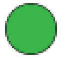
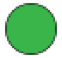
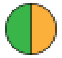
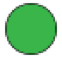
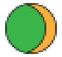
Coal + CCS

Includes pulverized coal (PC) technologies with carbon capture and storage (CCS)

Parameter	Rating	Reasoning
Construction Cost		Construction costs for new coal plants with CCS are relatively high compared to other options because of the added equipment costs for carbon capture and the reduced output capacity of the plant.
Electricity Cost		The higher capital cost, lower plant capacity, and lower efficiency of new coal plants with CCS lead to higher electricity production costs over their projected lifetimes compared to plants without CCS.
Capacity Factor		The capacity factor for a coal plant with CCS is similar to those of a coal plant without CCS.
Ramping Capability		Coal plants with CCS could have similar flexibility to coal plants without CCS. Ramping capability will ultimately depend on the design of a particular process and its control scheme.
Availability		Coal plants with CCS have similar availability to coal plants without CCS.
Total Area Use Intensity		Land area requirements for a coal plant with CCS are similar to those of a coal plant without CCS, but with a larger plant area for the CO_2 capture system.
Direct Water Use Intensity		Water requirements for a coal plant with CCS are similar to those of a coal plant without CCS, but with an increase for the CO_2 capture system.
Direct Greenhouse Gas (GHG) Emissions		Coal plants with CCS can be designed to capture more than 90% of the GHG emitted during coal combustion, resulting in much lower GHG emissions than a coal plant without CCS.
Other Direct Air Emissions		The air emissions of coal plants with CCS include the same pollutants as plants without CCS.
Direct Waste Products		Coal plants with CCS have similar volumes and types of waste as coal plants without CCS. In addition, there are waste products associated with the chemicals used in CO_2 capture.
Ease of Permitting		Coal plants with CCS will need to undergo environmental reviews for air emissions and water use, in addition to acquiring permits for CO_2 storage.
End of Life Considerations		Coal plants with CCS will require long term monitoring of stored CO_2 after decommissioning in addition to plant site remediation and monitoring of coal combustion product storage units in locations that have them.

Natural Gas

Includes simple-cycle combustion turbines (CT) and combined-cycle (CTCC) technologies

Parameter	Rating	Reasoning
Construction Cost		Construction costs for natural gas plants are lower due to their mature equipment designs and short construction durations.
Electricity Cost		Electricity production costs for new natural gas plants can be relatively low over their projected lifetimes, depending on the cost of natural gas and how often the plant operates.
Capacity Factor		The capacity factor of natural gas plants has risen steadily in the US as the cost of natural gas decreased and power plant operators have found it more economical to run combined cycle plants at higher capacity level.
Ramping Capability		Natural gas plants are extremely flexible. They can start up quickly to meet changes in demand and peak load and can operate at reduced power output to meet the needs of the grid.
Availability		Natural gas plants are highly reliable sources of electricity. They can operate either around the clock or be available to provide power during peak times of demand.
Total Area Use Intensity		Natural gas plants have a relatively small plant footprint for a given capacity. The gas well area is also relatively small, and the gas pipeline infrastructure is largely underground, resulting in low land use requirements.
Direct Water Use Intensity		Natural gas plants in a combined-cycle configuration require one-fourth to one-half the cooling water required for coal and nuclear plants. Simple-cycle natural gas plants also require much less water, primarily for water injection into the combustion turbine.
Direct Greenhouse Gas (GHG) Emissions		Natural gas has about one-half the carbon intensity of coal. In a combined-cycle configuration, natural gas plants emit about half as much GHG per megawatt hour as coal plants. GHG emissions from natural gas plants in a simple-cycle configuration are slightly higher per megawatt hour, but still significantly less than coal plants.
Other Direct Air Emissions		Natural gas does not contain solids and is typically processed to remove sulfur prior to combustion. Therefore, NOx emissions are the primary air pollutant from natural gas plants.
Direct Waste Products		Because there is no solid fuel combustion, natural gas plants do not produce solid waste. Waste products from natural gas plants are negligible.
Ease of Permitting		Natural gas plants need to meet similar air quality standards as coal plants, but due to lower GHG and other air emissions, it is relatively easier to obtain a permit
End of Life Considerations		Natural gas plants will require some resources for plant site remediation, but less than coal plants due to a lack of coal combustion product storage and other on-site waste products.

Natural Gas + CCS

Includes combined-cycle (CTCC) technologies with carbon capture and storage (CCS)

Parameter	Rating	Reasoning
Construction Cost		Construction costs for natural gas plants with CCS are higher than plants without CCS because of the added equipment costs for carbon capture and the reduced output capacity of the plant, but relatively lower than other technologies with CCS.
Electricity Cost		The increased capital cost and lower efficiency of natural gas plants with CCS lead to higher electricity production costs over their projected lifetimes compared to plants without CCS.
Capacity Factor		The capacity factor for a natural gas plant with CCS is similar to those of a natural gas plant without CCS.
Ramping Capability		Natural gas plants with CCS are likely to have slightly less flexibility than natural gas plants without CCS if high capture rates need to be maintained at the same time. Ramping capability will ultimately depend on the design of a particular process and its control scheme.
Availability		Natural gas plants with CCS have similar availability to natural gas plants without CCS.
Total Area Use Intensity		Land area requirements for a natural gas plant with CCS are similar to those of a natural gas plant without CCS, but with a larger plant area for the CO_2 capture system.
Direct Water Use Intensity		Water requirements for a natural gas plant with CCS are similar to those of a natural gas plant without CCS, but with an increase for the CO_2 capture system.
Direct Greenhouse Gas (GHG) Emissions		Natural gas plants with CCS can be designed to capture more than 90% of the GHG emitted during combustion, resulting in much lower GHG emissions than a natural gas power plant without CCS.
Other Direct Air Emissions		Air emissions of natural gas plants with CCS include the same pollutants as without CCS.
Direct Waste Products		There are no solid waste products involved with natural gas combustion, but there are waste products associated with chemicals used in CO_2 capture.
Ease of Permitting		The permitting process for natural gas plants with CCS could be similar to coal with CCS and may see similar timelines.
End of Life Considerations		Natural gas plants with CCS will require long term monitoring of stored CO_2 after decommissioning in addition to resources for plant site remediation.

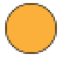
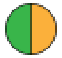
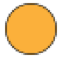
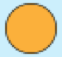
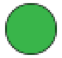
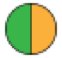
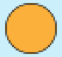
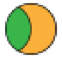
Biomass

Includes direct combustion biomass technologies

Parameter	Rating	Reasoning
Construction Cost		Construction costs for biomass plants can vary depending on the size of the plant, the type of biomass used, and the extent of biomass use.
Electricity Cost		Electricity production costs for new biomass plants are relatively high compared to other generation options and are largely dependent on the cost of available biomass feedstocks.
Capacity Factor		The capacity factor of biomass plants depends on several factors including availability of the feedstock and economic competitiveness.
Ramping Capability		Biomass plants have similar flexibility to coal plants. While they operate most efficiently at full power, there is some ability to operate at reduced power output. Following an outage, several hours are required for preheating the boiler before full operation can begin.
Availability		Biomass plants are typically available to operate around the clock, for months at a time.
Total Area Use Intensity		The land area required for a biomass generating unit is comparable to a coal plant. However, the biomass fuel growing, and collection area is roughly 1,000 times larger than the mining area required for a coal plant of similar capacity. If a biomass plant uses municipal wastes or agricultural wastes as fuel, then land area required would be similar to that of coal.
Direct Water Use Intensity		Biomass power plants require large amounts of water for operations, mostly to cool the steam that powers the turbine-generators to generate electricity. There also may be water requirements to grow biomass crops, although this varies with the feedstock source.
Direct Greenhouse Gas (GHG) Emissions		While there is debate over the CO_2 emissions intensity of biomass plants, the release of carbon from biomass sources during combustion is balanced to some degree by the uptake of carbon when the feedstock is grown, resulting in low-to-zero net GHG emissions over some period of time.
Other Direct Air Emissions		Emissions from biomass plants vary with the feedstock. Generally, biomass feedstocks have lower levels of sulfur, sulfur compounds, and mercury than coal. Primary air emissions from biomass plants are NOx and particulate matter.
Direct Waste Products		Waste products from biomass plants are similar to those from coal plants, including ash and wastewater, but typically do not include the same magnitude of waste products.
Ease of Permitting		Biomass plants need to meet similar air quality standards as coal plants, but due to lower GHG emissions, its relatively easier to obtain a permit.
End of Life Considerations		Biomass plants will require similar resources to a coal plant for site remediation.

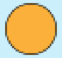
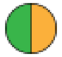
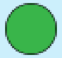
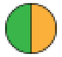
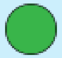
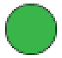
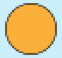
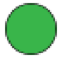
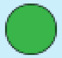
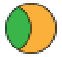
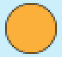
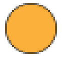
Biomass + CCS

Includes direct combustion biomass technologies with carbon capture and storage (CCS)

Parameter	Rating	Reasoning
Construction Cost		Construction costs for biomass plants with CCS are relatively high compared to other options because of the added equipment costs for carbon capture and the reduced output capacity of the plant.
Electricity Cost		The increased capital cost and lower efficiency of biomass plants with CCS lead to higher electricity production costs over their projected lifetimes compared to plants without CCS.
Capacity Factor		The capacity factor for a biomass plant with CCS is similar to those of a biomass plant without CCS.
Ramping Capability		Biomass plants with CCS could have similar flexibility to biomass plants without CCS. Ramping capability will ultimately depend on the design of a particular process and its control scheme.
Availability		Biomass plants with CCS have similar availability to biomass plants without CCS.
Total Area Use Intensity		Land area requirements for a biomass plant with CCS are similar to those of a biomass plant without CCS, but with a larger plant area for the CO_2 capture system.
Direct Water Use Intensity		Water requirements for a biomass plant with CCS are similar to those of a biomass plant without CCS, but with an increase for the CO_2 capture system.
Direct Greenhouse Gas (GHG) Emissions		Addition of CCS to a biomass plant can make it carbon negative by removing CO_2 from the air when the feedstock is grown and storing it underground after combustion.
Other Direct Air Emissions		Emissions from biomass plants with CCS would be similar to biomass without CCS.
Direct Waste Products		Biomass plants with CCS have similar volumes and types of waste as biomass plant without CCS. In addition, there are waste products associated with chemicals used on CO_2 capture.
Ease of Permitting		The permitting process for biomass plants with CCS could be similar to coal with CCS and may see similar timelines.
End of Life Considerations		Biomass plants with CCS will require long term monitoring of stored CO_2 after decommissioning in addition to resources for plant site remediation.

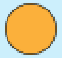
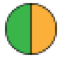
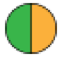
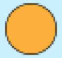
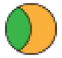
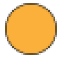
Conventional Nuclear

Includes GEN III+ reactors

Parameter	Rating	Reasoning
Construction Cost		Construction costs for nuclear plants are relatively high compared to other options because of the complexity of the designs, the robust facilities needed to provide safety, and the redundancy built into nuclear plant designs.
Electricity Cost		Electricity production costs for new nuclear plants are moderate over their projected lifetimes because of low fuel costs and the near-continuous operation of nuclear plants resulting in a large amount of electricity generated, offsetting their high capital costs.
Capacity Factor		Nuclear plants have the highest capacity factor of all generating technologies. They typically operate around the clock, for months at a time, often going one to two years between outages.
Ramping Capability		Nuclear plants have historically tended to operate at full power for best efficiency and lowest-cost generation. However, they can operate at reduced power, allowing for some flexibility and ramping capability. Following an outage, several hours to several days are required to start up the plant, depending on the reasons for the outage.
Availability		Nuclear plants are extremely reliable sources of electricity. They typically operate around the clock, for months at a time, often going one to two years between outages. Refueling and maintenance outages are scheduled during low demand seasons in the spring and fall.
Total Area Use Intensity		Nuclear plants have a relatively small plant footprint for the generating plant and its supporting facilities for a given capacity. The significant amount of energy released during fission results in fewer uranium mines and lower land use mining.
Direct Water Use Intensity		Nuclear power plants require large amounts of water for operations, mostly to cool the steam that powers the turbine-generators to generate electricity.
Direct Greenhouse Gas (GHG) Emissions		Because nuclear plants generate electricity from the energy released during the fission process, no combustion is involved. Unlike fossil plants, therefore, there are no GHG emissions.
Other Direct Air Emissions		Although radioactive emissions from a nuclear plant are possible in the event of an accident, emissions of other gases and pollutants are negligible from nuclear power production.
Direct Waste Products		Compared to waste products from certain other generation technologies - such as coal plants - waste volumes associated with nuclear are very small. However, the toxicity of these waste products, particularly used nuclear fuel, remains high for many years, and careful handling, storage, and long-term disposition is essential.
Ease of Permitting		In order to build a nuclear plant, a country must have a regulatory framework in place. Even with the framework present, it can take several years to acquire all the permits for operation of a nuclear power plant.
End of Life Considerations		Nuclear plants will require considerable resources to remediate the plant site for future use. Nuclear waste will require long-term monitoring/storage after plant decommissioning.

Small Modular Reactor (SMR) Nuclear

Includes Small Modular Light Water Reactors

Parameter	Rating	Reasoning
Construction Cost		Construction costs for SMRs are expected to be lower than large-scale nuclear due to reduced complexity and advanced safety designs, but are still relatively high compared to other technology options.
Electricity Cost		Electricity production costs for new SMR plants are moderate over their projected lifetimes because of low fuel costs, high plant output, and potential revenue streams from coproducts in addition to electricity.
Capacity Factor		SMRs can have similar capacity factors as conventional nuclear.
Ramping Capability		SMRs inherently have the same ramping flexibility as conventional nuclear reactors.
Availability		SMRs will have similar availability as conventional nuclear plants.
Total Area Use Intensity		SMRs have a relatively small plant footprint for the generating plant and its supporting facilities for a given capacity. The significant amount of energy released during fission results in fewer uranium mines and lower land use mining.
Direct Water Use Intensity		SMRs require large amounts of water for operations, mostly to cool the steam that powers the turbine-generators to generate electricity.
Direct Greenhouse Gas (GHG) Emissions		Because SMRs generate electricity from the energy released during the fission process, no combustion is involved. Unlike fossil plants, therefore, there are no GHG emissions.
Other Direct Air Emissions		Although radioactive emissions are possible in the event of an accident, emissions of other gases and pollutants are negligible from SMR power production.
Direct Waste Products		Direct waste for SMRs is comparable to conventional nuclear.
Ease of Permitting		The application, review, and approval process for SMRs can be similar to nuclear but pre-approvals and inherent safety features of these plants may expedite the process.
End of Life Considerations		SMRs will have similar end of life considerations as conventional nuclear.

Hydropower

Includes conventional hydro, small hydro, run-of-river or river in-stream, and pumped storage

Parameter	Rating	Reasoning
Construction Cost		Construction costs for hydro plants can vary significantly based on the type of plant and its location. Small conventional hydro in prime locations is generally less expensive than pumped hydro storage, which in turn is less expensive than run-of-river installations.
Electricity Cost		Electricity production costs for new hydro plants are relatively low compared to other technology options. Hydro plants often operate seasonally based on water resource availability, so may have lower electricity output than some technologies, but have a long lifetime, which can offset some of the higher capital costs.
Capacity Factor		The capacity factor of hydro plants varies depending on water availability and environmental regulations that could prevent the plant from running.
Ramping Capability		Hydro plants are extremely flexible. Their ability to start-up quickly and respond rapidly to changes in load are comparable to natural gas plants.
Availability		Hydro plant operation is limited by seasonal flows based on rainfall, snowpack, river icing, and temperature. Operation can also be limited by regulations regarding fish protection.
Total Area Use Intensity		The land area requirements for hydro plants vary with plant type. Run-of-river systems require minimal land area, pumped storage requires an area similar to that of a fossil plant, and conventional hydro requires a significant amount of land for its reservoir system.
Direct Water Use Intensity		Run-of-river hydro plants have negligible water loss, but conventional hydro plants with large reservoirs have water losses due to evaporation.
Direct Greenhouse Gas (GHG) Emissions		There are no GHG emissions related to combustion in hydro power generation. However, GHG can be emitted from the decomposition of organic matter and from bacteria in dam reservoirs.
Other Direct Air Emissions		Because there is no combustion involved in hydro power generation, there are no air emissions associated with power production.
Direct Waste Products		There are no waste products associated with power production from a hydro plant.
Ease of Permitting		The process for permitting a new hydro facility involves review from multiple federal, state and tribal agencies and may take several years.
End of Life Considerations		Hydro plant dams are likely to require indefinite maintenance as the structures will remain in place even after decommissioning.

Onshore Wind

Includes onshore wind

Parameter	Rating	Reasoning
Construction Cost		Construction costs for onshore wind farms are relatively low compared to other technology options.
Electricity Cost		The electricity output of a new wind farm will vary largely with regional wind resources, which will have a strong effect on electricity production costs. Current electricity production costs from new wind farms are relatively low given their construction in regions with favorable wind resources.
Capacity Factor		The capacity factor of onshore wind is dependent upon the wind resource available at the site. Most wind farms today are built in regions with high wind resources but will vary regionally.
Ramping Capability		Given proper conditions (including weather), onshore wind plants have some ability to ramp up and down for certain durations and magnitudes and have been relied upon to do so in some places to support grid reliability. They can be shut down or turned out of the wind to reduce plant output if needed.
Availability		Onshore wind plants are available to produce power only when the wind blows at sufficient speeds, which may not correspond with peak demand. Turbines must shut down at wind speeds exceeding their design range and power production may also be limited by transmission constraints in remote wind-rich areas.
Total Area Use Intensity		The land area required for a wind farm is roughly 85 times larger than the area required for a conventional nuclear plant of similar capacity. However, only 3-5% of the land is occupied by equipment and the remaining land could be used for agriculture or livestock grazing.
Direct Water Use Intensity		There is no water use required for power production at an onshore wind farm.
Direct Greenhouse Gas (GHG) Emissions		Because there is no combustion involved in onshore wind power generation, there are no GHG emissions.
Other Direct Air Emissions		Because there is no combustion involved in onshore wind power generation, there are no air emissions associated with power production.
Direct Waste Products		There are no waste products associated with power production from an onshore wind farm.
Ease of Permitting		Permitting for onshore wind takes less time than large-scale thermal plants with zoning permits and environmental analysis being a challenging part of the process.
End of Life Considerations		Restoration of land for an onshore wind farm is relatively simple due to a lack of operational waste product. Disposal or recycling of turbine blades and other materials will be required.

Offshore Wind

Includes fixed-bottom and floating offshore wind

Parameter	Rating	Reasoning
Construction Cost		Construction costs for offshore wind farms are higher than for onshore wind farms due to more robust design requirements for a marine environment and significant transmission assets needed to get electricity from the wind turbines to the shore. Construction costs are impacted by water depth and distance to shore of offshore wind plants, which influence the amount of materials required and installation time.
Electricity Cost		Electricity production costs for a new offshore wind farm are higher than onshore wind due to higher capital and operational costs. However, plant output is typically higher than onshore wind due to stronger offshore wind resources.
Capacity Factor		The capacity factor of offshore wind can be higher than that of onshore wind since wind tends to be stronger and more consistent over the ocean.
Ramping Capability		Given proper conditions (including weather), offshore wind plants have some ability to ramp up and down for certain durations and magnitudes and have been relied upon to do so in some places to support grid reliability. They can be shut down or turned out of the wind to reduce plant output if needed.
Availability		Offshore wind plants are available to produce power only when the wind blows at sufficient speeds, which may not correspond with peak demand. Turbines must shut down at wind speeds exceeding their design range.
Total Area Use Intensity		The area required for an offshore wind farm is similar to that of an onshore wind farm with the same capacity.
Direct Water Use Intensity		There is no water use required for power production at an offshore wind farm.
Direct Greenhouse Gas (GHG) Emissions		Because there is no combustion involved in offshore wind power generation, there are no GHG emissions.
Other Direct Air Emissions		Because there is no combustion involved in offshore wind power generation, there are no resulting air emissions associated with power production.
Direct Waste Products		There are no waste products associated with power production from an offshore wind farm.
Ease of Permitting		Permitting for offshore wind is more complicated than onshore wind, requires more agencies and public comments, and may take several years to acquire all the necessary permits.
End of Life Considerations		Restoration of ocean area for an offshore wind farm is relatively simple and may result in new artificial reefs for aquatic life. Disposal or recycling of turbine blades and other materials may be required. Since offshore wind is a relatively new technology, end of life considerations may change once the first wind farms reach the end of their life.

Solar PV

Includes fixed and tracking utility-scale photovoltaic (PV) systems

Parameter	Rating	Reasoning
Construction Cost		Construction costs for utility-scale solar PV plants are relatively low when compared to other technology options.
Electricity Cost		The electricity output of a PV plant varies largely with regional solar resources, which has a strong effect on electricity production costs. The lower capital costs of new PV plants and construction in relatively strong solar resource regions currently results in relatively low electricity production costs.
Capacity Factor		The capacity factor of solar PV plants is dependent on solar resource available at the site and can only operate during daylight hours, resulting in the lowest capacity factor of all technologies.
Ramping Capability		Given proper conditions (including weather), solar PV plants have some capability to vary output. Some new projects are aimed at flexibly curtailing PV plants for additional ramp control.
Availability		Solar PV plants are available to produce power only when the sun is shining and produce full power only during peak solar conditions. Power production is highly variable and changes rapidly with cloud cover.
Total Area Use Intensity		Utility-scale PV plants require roughly 10 times more land than the area of a conventional nuclear plant of similar capacity.
Direct Water Use Intensity		There is no water use required for power production from a PV plant. PV panels may require a limited amount of water for washing.
Direct Greenhouse Gas (GHG) Emissions		Because there is no combustion involved in solar PV power generation, there are no GHG emissions.
Other Direct Air Emissions		Because there is no combustion involved in solar PV power generation, there are no air emissions associated with power production.
Direct Waste Products		There are no waste products associated with power production from a solar PV plant.
Ease of Permitting		Permitting for solar PV takes less time than large-scale thermal plants with zoning permits being a challenging part of the process.
End of Life Considerations		Restoration of land for a solar PV plant is relatively simple due to a lack of operational waste product. Disposal or recycling of a large quantity of PV modules and other materials will be required.

Solar PV + Storage

Includes fixed and tracking utility-scale PV systems paired with battery energy storage

Parameter	Rating	Reasoning
Construction Cost		Construction costs for utility-scale solar PV plants paired with battery storage are higher than standalone PV plants due to the increased cost of the battery unit. Costs can vary based on the duration of battery storage included.
Electricity Cost		Electricity production costs for a PV plant paired with storage are slightly higher than PV without storage due to increased capital costs.
Capacity Factor		The capacity factor of PV plants with storage can be larger than that of standalone PV plants depending on design and the size of the storage equipment.
Ramping Capability		Solar PV with storage plants have the ability to operate flexibly by charging and discharging the batteries to control the output and respond to grid signals.
Availability		The addition of storage to a solar PV plant increases its ability to produce power when needed by storing electricity generated while the sun is shining and sending electricity to the grid when needed. The full availability of the plant is still dependent on the availability of solar resources, as well as the size and design of the storage.
Total Area Use Intensity		Land area requirements for a utility-scale PV plant with storage is similar to a solar PV without storage, but with a slightly larger plant area for the storage system.
Direct Water Use Intensity		There is no water use required for power production from a PV plant with storage. PV panels may require a limited amount of water for washing.
Direct Greenhouse Gas (GHG) Emissions		Because there is no combustion involved in solar PV power generation or energy storage, there are no GHG emissions.
Other Direct Air Emissions		Because there is no combustion involved in solar PV power generation and storage, there are no resulting air emissions.
Direct Waste Products		There are no waste products associated with power production from a solar PV plant with storage.
Ease of Permitting		Permitting for solar PV with storage takes less time than large-scale thermal plants with zoning permits being a challenging part of the process.
End of Life Considerations		Restoration of land for a solar PV with storage plant is relatively simple due to a lack of operational waste product, but disposal or recycling of a large quantity of PV modules, battery cells, and other materials will be required.

Concentrating Solar Power (CSP)

Includes parabolic trough and central receiver technologies with thermal energy storage

Parameter	Rating	Reasoning
Construction Cost		Construction costs for CSP plants are relatively high compared to other options and can vary widely based on the amount of storage capacity included.
Electricity Cost		Electricity production costs for CSP plants are moderate as higher plant output due to thermal energy storage somewhat offsets the higher capital costs.
Capacity Factor		CSP plants with storage can continue generating electricity after the sun is down with the potential to significantly increase capacity factor depending on the size and design of the storage.
Ramping Capability		CSP plants can provide some ramping capability given favorable conditions by charging and discharging storage.
Availability		While CSP operation depends on the availability of solar resources, a CSP plant can generate electricity and/or store heat when the sun is shining and can generate electricity from thermal storage when needed making the plant more dispatchable.
Total Area Use Intensity		The land area required for CSP is slightly larger than that for solar PV.
Direct Water Use Intensity		Many CSP plants are built in desert locations where water is scarce and are typically designed to have dry cooling; however, some water is required for mirror washing. If wet cooling is used, the water requirement is comparable to other thermal technologies, such as coal- and natural gas-fired power plants.
Direct Greenhouse Gas (GHG) Emissions		Because there is no combustion involved in CSP power generation, there are no GHG emissions.
Other Direct Air Emissions		Because there is no combustion involved in CSP power generation, there are no resulting air emissions.
Direct Waste Products		There are no waste products associated with power production from a CSP plant.
Ease of Permitting		Permitting for CSP takes less time than large-scale thermal plants with zoning permits including environmental analysis being a challenging part of the process.
End of Life Considerations		Restoration of land for a CSP plant is relatively simple due to a lack of operational waste product, though for parabolic trough systems, the synthetic oil would need to be disposed of safely. The molten salt in central receiver systems can be reused in other applications like fertilizer production.

Geothermal

Includes flash and binary geothermal technologies

Parameter	Rating	Reasoning
Construction Cost		Construction costs for geothermal plants vary widely based on the site-specific geothermal resource.
Electricity Cost		Electricity production costs for new geothermal plants can have a wide range due to their high dependence on the site-specific geothermal resource and the wide range of capital costs. Electricity production costs from a geothermal plant over its lifetime are expected to be relatively low due to no fuel cost and moderate operating costs.
Capacity Factor		Geothermal plants have very high capacity factors.
Ramping Capability		Geothermal plants have the ability to operate at full or reduced power output, but with some limitations on the minimum power output. Start-up time for a geothermal plant is faster than a coal plant because there is no boiler to preheat.
Availability		Geothermal plants can operate around the clock, for months at a time. Over time, geothermal resources can be depleted depending on the site-specific resource and reservoir management approach.
Total Area Use Intensity		Geothermal plants have a plant area similar to a natural gas plant, but the above-ground piping used for transporting geothermal steam is used over a wider area. However, most of the geothermal field area may be used for other purposes, such as agriculture or livestock grazing.
Direct Water Use Intensity		Geothermal plants typically use water from the geothermal reservoir that is unsuitable for other uses and, therefore, does not compete with conventional water resources. Cooling water may come from the geothermal reservoir, or additional water may be required.
Direct Greenhouse Gas (GHG) Emissions		There is no combustion involved in geothermal power generation and, therefore, there are no GHG emissions as a result of fuel combustion. However, there may be minimal releases of GHG from the geothermal reservoir.
Other Direct Air Emissions		Some hydrothermal fluids used at geothermal power plants contain hydrogen sulfide (H_2S), which can be captured if necessary. There are no emissions of NOx, SOx, or particulates from geothermal plants.
Direct Waste Products		Geothermal plants may have limited solid waste products associated with the treatment of geothermal fluids. Wastewater from a geothermal plant is usually re-injected into the wells.
Ease of Permitting		Permitting for geothermal plants can be subject to reviews by several regulatory agencies to address potential impacts to land use, water quality and others. Permitting can be more challenging depending on the geology of the site.
End of Life Considerations		Geothermal plants will require similar resources for plant site remediation as a natural gas plant.

Enhanced Geothermal Systems (EGS)

Includes near-hydrothermal field and deep enhanced geothermal systems

Parameter	Rating	Reasoning
Construction Cost		Construction costs for EGS vary widely based on the site-specific geothermal resource temperature and well productivity and depth. Construction costs are higher than conventional geothermal due to the need to create an engineered reservoir with special drilling and completion operations.
Electricity Cost		Electricity production costs for new EGS plants can have a wide range due to their high dependence on the site-specific geothermal resource and the wide range of capital costs. The increased capital cost leads to higher electricity production cost compared to conventional geothermal.
Capacity Factor		The capacity factor of EGS plants is similar to that of conventional geothermal plants.
Ramping Capability		EGS plants have similar ramping capability to conventional geothermal plants.
Availability		EGS plants have similar availability to conventional geothermal plants.
Total Area Use Intensity		The area required for EGS plants is similar to that of a conventional geothermal plant.
Direct Water Use Intensity		EGS plants require more water for operation than conventional geothermal plants.
Direct Greenhouse Gas (GHG) Emissions		GHG emissions for ESG would be similar to conventional geothermal.
Other Direct Air Emissions		Other direct air emissions for ESG would be similar to conventional geothermal.
Direct Waste Products		EGS plants may have limited solid waste products associated with the treatment of geothermal fluids. Wastewater from a EGS plant is usually re-injected into the wells.
Ease of Permitting		Permitting for EGS plants will be similar to conventional geothermal plants.
End of Life Considerations		EGS plants will require similar resources for plant site remediation as conventional geothermal plants.

ACKNOWLEDGMENTS

While based on sound expert knowledge from research programs across EPRI, they should be used for general information purposes only and do not represent a position from EPRI.

This product was developed with input from EPRI members and subject matter experts from across EPRI. Thank you to all the internal and external experts and stakeholders for your contributions to and shaping of this document.

PRINCIPAL INVESTIGATORS

R. BEDILION
rbedilion@epri.com

M. GUIMARAES
mguimaraes@epri.com

A. JAGDALE
ajagdale@epri.com

P. PATEL
ppatel@epri.com

KEY CONTRIBUTORS

A. BHOWN
G. BOORAS
C. BOYER
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EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com