Energy and System Design Mitigation Alternatives White Paper

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Background

This white paper explains the potential environmental impacts of energy alternatives to the construction and operation of a new nuclear generating facility, including energy alternatives both requiring and not requiring new generation capacity. The white paper also includes descriptions of potential system design mitigation alternatives that have the potential to reduce resource impacts associated with such projects. Depending on the design and/or capacity of the proposed facility, some of these alternatives may be relevant to the analysis required under Section 102 of the National Environmental Policy Act of 1969, as amended (42 U.S.C. § 4321 et seq.), while others may be eliminated from detailed analysis as economically or technically infeasible, or by not meeting the purpose and need for the proposed project. As technologies improve, the U.S. Nuclear Regulatory Commission (NRC) expects that some alternatives not currently viable may become viable at some time in the future; this white paper should be periodically updated to consider and incorporate the most up-to-date information and potential technological developments.

Much of the analysis in this white paper has been developed as a compilation from various new reactor environmental impact statements (EISs) prepared by the NRC staff, including NUREG-2179, *Environmental Impact Statement for the Combined License for the Bell Bend Nuclear Power Plant* (NRC and USACE 2016), as well as NUREG-1437, *Generic Environmental Impact Statement for License Renewal of Nuclear Plants*, Revision 0 (NRC 1996), and Revision 1 (NRC 2013). The 2013 revision to NUREG-1437 updated portions of the 1996 version, as necessary, but incorporated by reference the portions of the 1996 version that were still valid. This white paper contains references to the 1996 version of NUREG-1437 that have been reviewed and determined to still be valid.

The intent is that this white paper be incorporated by reference into future programmatic and site-specific project analyses as appropriate. While the white paper generally does not conclude that a given energy or system design alternative is or is not a viable alternative that should be analyzed in a project-level environmental assessment or EIS, it provides background and information as to the environmental impacts of these technologies, and how these technologies have been considered in previous reviews. While this information is primarily relevant to the construction and operation of (and license renewal for) large light-water nuclear power plants (NPPs), it may be relevant to analyses of smaller nuclear facilities with smaller power outputs and footprints.

In at least 24 EISs published since 2006, the NRC has analyzed various alternative energies in large light-water NPP reviews but has determined that these energy alternatives were not environmentally preferable to the proposed action. While some of the technologies discussed in this white paper could potentially be viable alternatives to smaller proposed facilities (such as increased potential for use of wind and solar energy as a viable replacement), other technologies may be infeasible for such an application. As such, determination of an appropriate range of reasonable alternatives for any given project must be identified during project-specific reviews and may differ across various project types, locations, and technologies. The need for this comparison may be even more important for smaller reactors, which have not been extensively analyzed in previous EISs.

The NRC relies on many sources of information to determine which alternatives are available and commercially viable. The U.S. Department of Energy's (DOE's) Energy Information Administration (EIA) maintains the official energy statistics for the federal government. Along with other sources, the NRC commonly uses information from EIA reports, including the *Electric Power Annual*, *Annual Energy Review*, *Renewable Energy Annual*, *Renewable and Alternative Fuels*, *Annual Energy Outlook*, and *Assumptions to the Annual Energy Outlook* to identify alternatives to the proposed action. The NRC will often consider the existing portfolio of electric generating technologies in the State or utility service area in which a reactor(s) is located, along with State and Federal policies that may promote or oppose certain alternatives. The NRC may also use EIA's State Energy Profiles as well as State, regional, and, in some cases, utility- or system-level assessments of energy resources and projections to identify alternatives for consideration. For example, many public utility commissions require regulated utilities to develop an integrated resource plan that evaluates the energy needs and the mix of energy sources discussed in this paper that can meet that need. Because the public utilities commissions have regulatory authority over the energy supply, the NRC should consider the utility-level analysis in the integrated resource plan.

Energy Alternatives

For any energy alternative, the staff should first determine if the alternative meets the purpose and need for the project. The staff should concisely document the rationale for alternatives not meeting the purpose and need for the project, and no further analysis of the alternative is needed.

1.1 Alternatives not Requiring New Generating Capacity

Four alternatives to constructing new generating capacity are to:

- implement conservation and demand-side management programs
- extend the service life of existing plants within the power system
- reactivate retired plants
- purchase power from other utilities or power generators

These alternatives are discussed in greater detail in the following sections.

1.1.1 Conservation and Demand-Side Management

The need for alternative or replacement power can precipitate or invigorate conservation and energy efficiency efforts designed to either reduce electricity demand at the retail level or alter the shape of the electricity load. All such efforts are broadly categorized as demand-side management (DSM), although DSM can also include measures that increase energy consumption or cause consumers to switch from fuels like natural gas to electricity (DOE/EIA 2019a). Utility companies use DSM to reduce consumer energy usage, either through energy efficiency measures or through demand response, which attempts to shift consumer demand during times of low or high energy use (DOE/EIA 2019a). Conservation and energy efficiency measures may be encouraged by the same company that operates an NPP when that company also serves residential and business ratepayers. In other cases, the measures may be offered by other load-serving entities, State-based programs, third-party service providers and aggregators, or even transmission operators. Programs include, but are not limited to, incentives for equipment upgrades, improved codes and standards, rebates or rate reductions in exchange for allowing a utility to control or curtail the use of high-consumption appliances (like air conditioners) or equipment, training in efficient operation of building heating and lighting systems, direct payments in consideration for avoided consumption, or use of price signals to shift consumption away from peak times (NRC 2013).

EIA collected data on DSM for the final time in 2012 (DOE/EIA 2019b). This data showed that total peak load reductions due to DSM programs was 42,124 MW in 2012, comprising a combination of energy efficiency and load management activities.

EIA data show that historically, residential electricity consumers have been responsible for the majority of peak load reductions achieved by conservation and energy efficiency programs. However, participation in most conservation programs is voluntary, and the existence of a program does not guarantee that reductions in electricity demand would occur. Nevertheless, energy conservation programs in general can result in significant reductions in demand. Recent legislative actions in some States requiring the establishment of programs such as “net metering” and technological advances to the electric transmission network, the “smart grid,” have facilitated greater degrees of participation in energy conservation programs, especially among residential customers.

Conservation and energy efficiency programs may reduce overall environmental impacts associated with energy production.

While the energy conservation or energy efficiency potential in the United States is substantial, NRC staff is not aware of any cases where an energy efficiency or conservation program has been implemented expressly to replace or offset a large, baseload generation station. While the potential to replace a large baseload generator may exist in some locations, it is more likely that conservation and energy efficiency programs will not replace or offset large, baseload generation stations and will therefore not be a reasonable stand-alone alternative. However, such programs may play an important role in the evaluation of a combination of alternatives (NRC 2013).

Improved energy efficiency and DSM strategies can potentially cost less than construction of new generation and provide a hedge against market, fuel, and environmental risks. Generally, NRC has concluded that despite the existence of conservation and DSM programs, there is a justified need for power because the analysis of the need for a new generating facility has already accounted for any savings from such programs. DSM is generally most viable for, but not an alternative to, larger reactors designed to power the electric grid; DSM may be a viable alternative for potential smaller, modular, or transportable nuclear reactors, designed to power a particular facility or installation, or to power an isolated community.

1.1.2 Extending Power Plant Operating Life

To extend plant life, older currently operating fossil-fueled plants, predominately coal- and natural gas-fired, are likely to need refurbishing. Typically, such plants would be old enough that, as refurbished plants, they would be viewed as new sources, subject to the current complement of regulatory controls on air emissions and waste management (DOE/EIA 2020a). Meeting current environmental requirements would be costly. In addition, a power generating company would have already considered this option prior to making the decision to build a new plant.

1.1.3 Reactivating Retired Power Plants

Based on a review of recent new reactor EISs, if the proposed action is to construct and operate a large light-water reactor (LLWR), it is unlikely that reactivating any individual retired unit would be able to meet the proposed output of a new LLWR unit, and it would be unlikely that reactivating a combination of retired units could be developed to meet this output and successfully meet applicable environmental requirements (e.g., Clean Air Act [CAA]; 42 U.S.C. § 7401 et seq.).

The environmental impacts of any reactivation scenario would be bounded by the construction impacts associated with refurbishment, in addition to operational impacts associated with emissions from the facility (generally coal and natural gas, which the NRC concluded in recent new reactor EISs (e.g., NUREG-2179; NRC and USACE 2016), are not environmentally preferable to construction of a new nuclear facility). Given both these refurbishment costs and the environmental impacts of operating such facilities, in general, reactivating retired generating plants would not be a reasonable alternative to providing new baseload power-generation capacity with a new NPP.

1.1.4 Purchased Power

Bulk electricity purchases currently take place within geographic regions established by the North American Electric Reliability Corporation (NERC), the authorized Electric Reliability Organization for the United States. Also, interconnections exist between NERC regions that allow for power exchanges between the regions when necessary to satisfy short-term demand. The NRC recognizes the possibility that replacement power may be imported from outside an NPP's service area, which may or may not require importing power from another region. In most instances, importing power from distant generating sources would have little or no measurable environmental impact in the vicinity of the NPP; however, it could cause environmental impacts where the power is generated or anywhere along the transmission route. Importing power from outside a particular region or purchasing it from a generator in the same region are possible sources of replacement power (NRC 2013).

Incremental power transfer capacities have been established between grid segments both within and across NERC regions, and modest amounts of power routinely transfer across those points. Such capabilities were established to ensure overall grid stability and reliability under both routine and non-routine conditions. In contrast, long-term transfers of utility-scale power from outside of a given power plant's region may require modification of one or more existing transmission grid segments (as well as modifications to substations and power synchronization equipment) and could require construction of new transmission line segments. New transmission lines may be required for long-term purchased power from within the same NERC region as well, but the need is highly situation-dependent. Further, efforts by transmission operators to provide a price signal for transmission congestion through locational-marginal pricing would, over the long run, provide an incentive for power purchases closer to the existing power plant or construction of new capacity nearer the existing power plant. In general, the more geographically distant the exporting source, the greater the likelihood that new or modified interconnecting transmission line segments would be necessary. Power purchase agreements would also be used in emergency situations or to alleviate a capacity shortfall in the near term (NRC 2013).

Because purchasing power from elsewhere simply shifts the environmental impacts to another location, and because the power generating company would have already determined whether such a purchase was cost-effective, the NRC has typically determined that such purchases are not environmentally preferable to the construction and operation of a new NPP.

1.2 New Generation Alternatives

Potential new generation alternative energies are described in the following sections. A summary table of these energy alternative technologies and their resource impacts as compared to nuclear energy development is included in Appendix A.

1.2.1 Coal

The environmental impacts of constructing a typical coal-fired steam plant are well known because coal is a major type of central generating technology in the United States. It is expected that any new coal-fired plants would be sited in a rural area, because of impacts associated with pollutants and land requirements that make it infeasible to site in an urban area. On average, a 1000 MW coal plant may require 500 acres of land cover, excluding that required for mining and other fuel cycle impacts (Fthenakis and Kim 2009). Ecological impacts could be large, and important cultural sites could be encountered, particularly near rivers. With this much land being cleared, some erosion and sedimentation would be expected. Considerable fugitive dust emissions during construction would affect air quality temporarily, and the quantity of construction debris could also be substantial. Visual impacts from such a large construction effort in a rural area could be substantial. Socioeconomic impacts at a rural site would be larger than at an urban site because more of the large workforce that may need to move to the area. Such impacts are most significant at very remote sites where accommodations may be nonexistent, and the large majority of workers must move to work on the plant. Transmission line construction, if necessary, would add to virtually all these impacts. Siting a new coal-fired plant where another operating power plant is located would reduce many construction impacts, thereby reducing the initial damage to the environment and possibly eliminating the need for new transmission lines. Such co-locating would depend on factors such as location of load centers, environmental restrictions, and site characteristics (NRC 1996).

Regarding operating impacts of coal plants, concerns over adverse human health effects from coal combustion have led to important Federal legislation, such as the CAA. Coal emits higher amounts of nitrogen oxides, carbon dioxide (CO_2), sulfur dioxide (SO_2), heavy metals, and particulate matter than do other fuel sources (DOE/EIA 2020c). Radionuclides, which naturally exist in coal and fly ash (Gasparotto and Martinello 2021), would also be emitted (Gabbard 1993). Public health risks such as chronic obstructive pulmonary disease, asthma, lung cancer, and respiratory infection have been tied to inhalation of emissions from coal plants (Gasparotto and Martinello 2021). Adverse impacts associated with coal mining could include air quality impacts from fugitive dust, water quality impacts from acidic runoff, and visual resource impacts (Finkelman et al. 2021). Substantial solid waste would be produced, especially fly ash and scrubber sludge. On average, for every six tons of coal burned, one ton of coal ash is produced (Brown et al. 2017). An estimated 8,900 ha (22,000 acres) for mining the coal and disposing of waste could be committed to supporting a coal plant over its operational life. Regarding impacts to aquatic organisms, if once-through cooling systems are installed, risk of impingement or entrainment of such organisms would occur. These risks can be lessened if recirculating cooling systems are installed (DOE/EIA 2014b).

Socioeconomic benefits of constructing and operating a coal plant could be considerable for surrounding communities in the form of several hundred jobs, substantial tax revenues, and plant spending (Hill and Associates 2007). Additional benefits include the several hundred mining jobs and tax revenues that would accompany the coal mining (NRC 1996).

Projections for the amount of electricity produced from coal in the future vary widely across planning scenarios, primarily due to cost uncertainties associated with anticipated future environmental regulations such as cap-and-trade regulations for nitrogen dioxide (NO_2), SO_2 and regulation of greenhouse gas emissions, primarily CO_2. The EIA projects that between 2019 and 2025, coal-fired generation will decrease by 26 percent under a reference case. This decrease is a result of competitively priced natural gas and increasing renewables generation, in addition to requirements to comply with the Affordable Clean Energy Rule[1] (DOE/EIA 2020a).

Advanced coal technologies will likely become increasingly important as regulations on power plant emissions evolve, including under the CAA and the Clean Water Act (33 U.S.C. § 1251 et seq.). Technologies often referred to as “clean coal technologies,” which include coal cleaning processes, coal gasification technologies, improved combustion technologies, and improved devices for capturing pollutants, may reduce impacts associated with a coal-fired plant (NRC 2013). The EIA assumes that by 2025, coal plants are expected to either invest in heat rate improvement technologies or will be retired. The remaining coal plants would therefore be more efficient than under a current scenario. Expected low natural gas prices are expected to contribute to the retirement of existing coal-fired plants (DOE/EIA 2020a).

For very small reactors, a coal-fired power plant may not be an alternative because it may be infeasible to build a coal-fired plant to that scale. The National Energy Technology Laboratory is currently evaluating conceptual designs for smaller coal plants (NETL 2019).

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[1] The final Affordable Clean Energy Rule was published in the *Federal Register* on July 8, 2019 (84 FR 32520). However, on January 19, 2021, the D.C. Circuit vacated the Affordable Clean Energy Rule and remanded to the Environmental Protection Agency for further proceedings consistent with its opinion.

1.2.2 Natural Gas

The most common types of natural gas-fired plants are combustion turbine and combined-cycle. The combustion turbine involves hot gases which drive the generator and are then used to run the compressor. A combined-cycle power system typically uses a gas turbine to drive an electrical generator, recovering waste heat from the turbine exhaust to generate steam that drives a steam turbine-generator. Natural gas-fired combined-cycle generating technology has evolved over the past few decades, increasing from 20 MW units in the early 1960s to 200 MW by the late 1990s to 320 MW for today's advanced natural-gas combined-cycle units. Since 2016, 31 percent of new gas-powered plants constructed use advanced natural gas-fired combined-cycle units, increasing efficiency and decreasing capital construction costs (DOE/EIA 2019c).

Land-use requirements for gas-fired plants are small at 45 ha (110 acres) for a 1000-MW(e) plant; thus land-dependent ecological, aesthetic, erosion, and cultural impacts should be small unless site-specific factors indicate a particular sensitivity for some environmental resource. Siting at a greenfield location would require new transmission lines and increased land-related impacts, whereas co-locating the gas-fired plant with an existing power plant would help reduce land-related impacts. Due to the smaller size of the gas-fired plant, the construction work force is small for a central generating technology, and gas-fired plants are not usually sited in remote areas where community impacts would be most adverse. Also, gas-fired plants, particularly combined cycle and gas turbine, take much less time to construct than other plants. Additional land would be required for wells, collection stations, and pipelines to bring the natural gas to the generating facility. Impacts would be typical of those associated with land clearance (NRC 1996).

The environmental impacts of operating gas-fired plants are generally less than those of other fossil fuel technologies of equal capacity. The total volume of water consumed at natural gas power plants is about half of that consumed at a similarly sized coal plant (Kondash et al. 2019). There are potential impacts to aquatic biota through impingement and entrainment and increased water temperatures in receiving water bodies; however, these impacts can be lessened with the installation of recirculating cooling systems (DOE/EIA 2014b). Generally, air quality impacts for all natural gas technologies are less than for other fossil technologies because lesser amounts of pollutants like CO_2 are emitted (DOE/EIA 2021b) and SO_2 is emitted in small quantities, if at all (EPA 1998). Solid waste is minimal, and is associated with the byproducts from emission controls (Brown et al. 2017). The workforce would be expected to be the smallest of any nonrenewable technology, as would local purchases and local tax revenues (NRC 1996).

As of 2019, natural gas technologies represented 37 percent of electricity generation, outpacing coal (24 percent), nuclear (19 percent), and renewables (19 percent). Based on reference case projections, natural gas generation as a proportion of electricity generation is expected to remain relatively constant (36 percent in 2050), with decreases in coal and nuclear being replaced by increases in renewables (DOE/EIA 2020a).

The environmental impacts from natural gas-generation alternatives were evaluated in the 1996 version of NUREG-1437 (NRC 1996) and in numerous operating reactor license renewal reviews, including the Susquehanna Steam Electric Station Units 1 and 2 license renewal application final supplemental EIS (NRC 2009). In that final supplemental EIS, the NRC staff assumed that a natural gas-fired plant of a size equivalent to a LLWR NPP would need six units with a net capacity of 400 MW(e) per unit, and would emit criteria, hazardous, and greenhouse gas air pollutants, but generally in smaller quantities relative to a coal-fired alternative.

1.2.3 Oil

Constructing a 1000-MW(e) oil-fired power plant would have the same types of environmental impacts as constructing other large central generating power stations. Relatively small land requirements of an estimated 50 ha (120 acres), however, would be expected to reduce other resource impacts that tend to follow land-use impacts: ecological, aesthetic, air quality, water quality, and cultural. As land-use requirements decrease, erosion, loss of habitat, and negative aesthetic impacts generally decrease as well. Expected socioeconomic impacts should not be high because of the moderate size of the construction work force, and oil-fired plants typically are not sited in remote areas or otherwise away from larger communities that are on pipelines or near where the oil is refined, consumed, or imported. Transmission lines for a greenfield site likely would increase land-dependent impacts in approximate proportion to the transmission/generation acreage. Land-use related impacts could be reduced if the oil-fired plant were co-located with an existing power plant. Additional land would be needed for oil wells and support facilities that would provide the generating plant with fuel. Impacts would likely be similar to those of other land clearing activities (NRC 1996).

Operating oil-fired power plants would cause the same types of environmental impacts as comparably sized coal-fired plants. Because they typically use the same cooling systems, water use and related impacts to water quality and aquatic biota would be similar. Regulated pollutants, CO_2, and small amounts of radionuclides would be emitted, although in lesser quantities than from an equivalent-size coal-fired plant. Solid waste is generated associated with the use of environmental controls for air pollution mitigation, if installed (Brown et al. 2017). Attendant impacts associated with combustion of the oil would include acid precipitation, global warming, and some increased risk of health problems, similar to the health effects caused by combustion of coal. Employment, tax revenues, and local purchases would be positive socioeconomic impacts for local communities.

According to the EIA, in 2016, only 3 percent of utility-scale generators used petroleum as a primary fuel, producing less than 1 percent of total electricity generation. These plants are on average 38 years old, with roughly 70 percent of the capacity constructed prior to 1980. In general, oil plants are located in coastal states where marine modes of oil transportation are competitive with transportation of coal by rail. Oil-fired generation is more expensive than the nuclear, natural gas-fired, or coal-fired generation options. The high cost of oil has resulted in a decline in its use for electricity generation (DOE/EIA 2017).

1.2.4 Wind Power

Land-based wind energy is assumed to have a capacity factor of around 28–35 percent (DOE/EIA 2020d), along with a land requirement of 60 acres/MW of installed capacity (NRC and USACE 2016). The relatively low-capacity factor of wind power as compared to baseload power sources means that it would operate less frequently at full power. As a result, to generate the same average amount of energy (megawatt-hours) as a 1000 MW(e) baseload plant would require the installation of almost 3000 MW(e) of wind turbines, causing significant impacts to land use.

The earth-moving that might be required to clear such a large amount of land would destroy much of the natural environment in affected areas (e.g., coastal, mountainous, or plains), where wind velocities are highest. Erosion and sedimentation, while controllable, would still occur and would adversely affect land and water resources. The visual impact of such extended land clearing would be quite noticeable and would be a negative aesthetic consequence. Short-term air quality impacts from fugitive dust and equipment exhaust would occur with such extensive activities, and considerable vegetation debris could require disposal. Disturbance of such a large amount of land likely would reveal cultural resources that would require protection. Each of these site impacts would be magnified because of the new transmission lines that are almost always required for greenfield sites. Agricultural land could also be committed to the siting of wind energy facilities in some areas. Adverse impacts could still occur where land is taken out of production, but the acreage lost would likely be less than with unimproved land (NRC 1996).

The projected impacts of operating wind energy facilities are less than those expected from construction. The same amount of land would still be committed to wind generation, but the machines would occupy less than 10 percent of it, freeing up most of the remainder for agricultural or some other compatible use. The aesthetic impact of several hundred wind turbines over a large area likely would strike many observers as obtrusive. The noise from such equipment likely would reinforce these negative opinions. Birds are likely to collide with the turbines, and wind energy developers should consider migration areas and nesting locations when sites for wind energy facilities are selected. In terms of positive environmental impacts, wind power plants would have little effect on water and air quality and would generate very little waste. Human health impacts such as dizziness, headaches, and sleep disturbance have been reported by residents close to wind energy facilities; however, the scientific evidence to date has not demonstrated a direct causal link between wind turbine operations and negative human health impacts.

Offshore wind farms can have higher capacity factors and use larger turbines. For example, the proposed Cape Wind Energy Project, that would have been located in Nantucket Sound off of Cape Cod, Massachusetts, would have used 130 wind turbines rated at 3.6 MW(e) each for an electrical generation capacity of 468 MW(e). The project would have delivered, on average, 1,600 GWh/yr to the grid (including consideration of line losses from the turbines to shore), for an average effective capacity factor of 39 percent (DOI 2009). The project would have occupied an area of about 25 mi^2 (16,000 ac), or roughly 120 ac per turbine (or about 34 ac per installed megawatt) (NRC and USACE 2016). In 2018 the project owner relinquished its lease (BOEM 2020). As of early 2020 the only operating offshore wind farm in the U.S. is a 30 MW(e) demonstration project near Block Island, Rhode Island (Proctor 2020).

Wind turbines generally can serve as an intermittent power supply, as they do not operate when there is no wind (NPCC 2010). Wind power, in conjunction with energy storage mechanisms (some of which are described in Section 1.2.11, Combination of Alternatives) might serve as a means of providing baseload power. Alternatively, the power company could install wind turbines to match the planned output of the NPP and also build and maintain a backup power source (e.g., a natural gas plant) to provide power when the wind farm is not operating at full capacity. This configuration would involve a smaller commitment of land for the wind turbines but would also involve the cost and impacts of building two power plants: the wind turbines and the natural gas plant.

1.2.5 Solar Power

Solar power technologies that are commercially viable for the production of electricity include solar thermal and photovoltaic (PV). Solar thermal or concentrating solar power (CSP) systems are designed to concentrate the sun’s heat energy by as much as 10,000 times to generate high temperatures. PV systems use semiconductors in solar cells that convert photons of solar energy to direct current (DC) electricity. Some PV designs also use concentrating devices to enhance power production by increasing the energy reaching a given solar cell. In recent years, solar power has enjoyed strong growth in many parts of the world. There is great interest in deploying these systems in the United States, especially in those portions of the six southwestern States with high-value solar resources (California, Nevada, Utah, Colorado, New Mexico, and Arizona), on lands controlled by the U.S. Department of Interior’s Bureau of Land Management (BLM), and in States with solar “set-asides” in their renewable portfolio standards(NRC 2013).

Although the highest-value solar resources exist in the desert regions of the Southwest, solar resources of adequate quality to support utility-scale solar energy facilities are located in other parts of the country as well.

While CSP relies on direct normal insolation, PV can respond to direct as well as reflected or refracted sunlight. Solar intensity varies throughout the lower 48 States, making the use of PV technology feasible—to varying extents—throughout the country. Nonetheless, the highest direct normal insolation values are found in the southwestern States, making that geographic region the preferred location for CSP facilities (NRC 2013).

The construction impacts of building a solar thermal central generating station would stem from the amount of land required to generate electricity, with the resulting destruction of whatever wildlife habitat or agricultural values the land provided (Ong et al. 2013). A greenfield site or sites, along with new transmission lines, probably would be required because few existing facilities would have sufficient land for such an endeavor. The visual impact of such clearing, even in desert landscapes where solar thermal technology is most competitive, would be regarded by many observers as an obvious negative aesthetic impact. Potential impacts to cultural resources could be considerable because of the large amount of land affected, and care would need to be taken to identify such resources before construction. Some erosion and sedimentation would likely occur during land clearance. Considerable short-term impacts to air quality would occur from dust and vehicle exhaust, and vegetation and other debris would require disposal, perhaps through on-site burning. The size of the construction work force that would be needed is unknown, but it could be reduced through the use of prefabricated components and a modular construction approach. Adverse socioeconomic impacts could be reduced in this fashion (NRC 1996).

The operating impacts of a large solar thermal facility also would revolve around land resources dedicated to the plant. No other uses would be compatible because the solar thermal collectors would take up most of the space. Construction-initiated adverse aesthetic impacts and habitat losses and any accompanying risks to threatened and endangered species would continue. There should be few operating impacts to air quality, human health, solid waste, and cultural resources. Water quality would be affected if water were used as a cooling agent in an arid environment where it is in short supply or water runoff from the collectors were uncontrolled and sedimentation damaged water bodies. For solar thermal facilities that use a steam cycle to generate electricity, water use impacts would be similar to that from an NPP with the same power output. Socioeconomic benefits should be small compared with those communities that host large nonrenewable generating stations. Work forces and local purchases would be small. However, the likely high cost—and high assessed value—of solar thermal facilities could lead to substantial property tax revenues (NRC 1996).

The land commitment for solar PV would also be much larger than for an NPP. Land requirements are approximately 6.2 acres/MW(e). In addition, the capacity factor for solar PV power operation ranges between 14-33 percent (NRC 2016). Similar to wind power, this relatively low-capacity factor as compared to baseload power sources means that the solar plant would operate less frequently at full power. Assuming a capacity factor of 25 percent, to generate the same average amount of energy (megawatt-hours) as a 1000 MW(e) baseload plant would require the installation of almost 4000 MW(e) of solar, causing significant impacts to land use.

If new transmission lines are required, further land would be required. Such a facility would have significant impacts to land use, aesthetics, and terrestrial ecology. Potential construction-related impacts to cultural resources could be considerable because of the large amount of land affected, and care would need to be taken to identify such resources before construction. Some erosion and sedimentation would likely occur during land clearance. Considerable short-term impacts to air quality would occur from dust and vehicle exhaust, and vegetation and other debris would require disposal, perhaps through on-site burning.

Because of the low conversion efficiency and the low-capacity factor (dependent on sunshine), a means to store large quantities of energy for distribution would be needed. Energy storage technologies are discussed in Section 1.2.11, Combination of Alternatives.

1.2.6 Hydropower

Currently, there are approximately 2,000 operating hydroelectric facilities in the United States. Hydroelectric technology operates by capturing the energy of flowing water and directing it to a turbine and generator to produce electricity. There are two fundamental hydropower facility designs: “run-of-the-river” facilities that simply redirect the natural flow of a river, stream, or canal through a hydroelectric facility, and “store-and-release” facilities that block the flow of the river by using dams that cause the water to accumulate in an upstream reservoir (NRC 2013). A separate type of hydropower is pumped storage, which is a type of hydroelectric plant that generates energy during peak load periods by using water previously pumped into an elevated storage reservoir during off-peak periods.

The potential for future construction of large dams has diminished due to increased public concerns over flooding, habitat alteration and loss, and destruction of natural river courses. Because of the amount of land affected (an estimated 1600 mi^2 for a rating of 1000 MW(e)), there can also be construction-related impacts to cultural resources. Additional demands for river water have also reduced water flow (NRC 2013). Hydropower generally has between a 40-50 percent capacity factor, higher than those of solar or wind, but lower than power plants operated for baseload power generation (DOE/EIA 2021a).

Large hydroelectric facilities constructed on major rivers can have peak power capacities as high as 10,000 MW(e). However, river flow conditions and other circumstances and factors (e.g., spawning periods of anadromous fish) often require dam operators to divert river flow around power-generating turbines over various periods of time, thereby reducing the amount of power generated (NRC 2013).

1.2.7 Ocean Wave and Current Energy

A variety of ocean wave energy technologies have been considered. Point absorbers and attenuators allow waves to interact with a floating buoy. The wave motion is converted into mechanical energy to drive a generator. Overtopping devices trap some portion of an incident wave at a higher elevation than the average height of the surrounding sea surface, while terminators allow waves to enter a tube, compressing air that is then used to drive a generator. In general, technologies that harness the energy of ocean waves are in their infancy and have not been used at utility scale. These technologies may become commercially viable in the near future. A point absorber facility, for example, has been proposed off the coast of Oregon. Similarly, feasibility studies and prototype tests for wave energy capture devices have been conducted for locations off the coasts of Hawaii, Oregon, California, Massachusetts, and Maine. Ocean current energy technology is also in its infancy. Existing prototypes capture ocean current energy with submerged turbines that are similar to wind turbines. Although the functions of ocean turbines and wind turbines are similar (both derive power from moving fluids), ocean turbines have substantially greater power generating capacity because the energy contained in moving water is approximately 800 times greater than in air. In relatively constant currents with average velocities of 5.6 km/h (3.5 mph) or variable tidal currents averaging 9.3 km/h (5.8 mph), ocean turbines can produce sufficient capacity factors for baseload demand. Various ocean turbine designs are undergoing research, development, and demonstration (NRC 2013).

Because these technologies are not yet in use on a commercial scale, these technologies are generally not considered feasible alternatives to construction of a new nuclear power-generation facility.

1.2.8 Geothermal Energy

Geothermal energy is energy in the form of heat contained below the Earth’s surface in hydrothermal zones (hot water or steam trapped in an aquifer), hot and dry geologic formations (referred to as hot dry rock or engineered geothermal systems [EGS]), or in geopressurized resources (hot brine aquifers existing under pressure). Thus far, hydrothermal sources are the only geothermal energy resources that have been in commercial use (NRC 2013).

The technical approaches to exploiting geothermal energy resources are quite similar. First, crews drill wells down to the heated resources. Next, the wells raise hot water or steam to the surface where the heat energy can be used to generate electricity. EGS differs in that crews must first fracture a hot, dry rock formation and then inject a heat transfer fluid (typically water). They then recover the heated fluid from the formation through the well and then use the heated fluid to produce steam—and subsequently electricity—in a conventional steam turbine generator (NRC 2013).

Most domestic geothermal resources exist in the western United States (NRC 2013). To date, the greatest amount of electricity produced by geothermal technologies has occurred in California. As of 2019, geothermal comprised 2% of all renewable electricity generation in the United States and is expected to increase to 3% by 2050. Approximately half of the existing 2.5 GW of operating geothermal capacity in the U.S. came online in the 1980s, although three plants with a combined capacity of 115 MW are expected to come online in 2020 (DOE/EIA 2014a).

Geothermal reservoir mapping in the western States suggests there is still significant untapped potential. EIA projects that geothermal electricity generation could more than quadruple between 2012 and 2040 (increasing to over 67,000 GWh), helping California and other states with renewable portfolio standards satisfy their mandated renewable generation requirements (DOE/EIA 2014a).

U.S. Geological Survey (USGS) assessments of geothermal capacities in the western States are also high. According to USGS, western states have 241 identified moderate temperature (90–150°C/194–302°F) and high-temperature (greater than 150°C/302°F) geothermal resources with a power generating capacity potential of 9,057 MW(e) from identified geothermal resources, an additional mean generation capacity potential of 30,033 MW(e) from undiscovered geothermal resources, and an additional 517,800 MW(e) from the application of EGS technology (USGS 2008). The USGS determined that California has the largest identified resource capacity (59.67 percent of identified resources), followed by Nevada (15.36 percent). California and Nevada also have the two largest shares of undiscovered resources with 37.8 percent and 14.5 percent, respectively.

Using current technologies (which included EGS where appropriate) and the exploitation of both identified and yet undiscovered resources, the USGS estimates that California and Nevada have the potential for additional geothermal power development on private and public lands of 9,282 MW(e) and 2,551 MW(e), respectively (USGS 2008).

A geothermal energy facility could be a reasonable alternative in areas in which the resource is available. However, because of the limited geographic locations of the geothermal resource, in most cases a geothermal energy facility would not be a reasonable alternative to construction and operation of an NPP supplying baseload electricity in most locations in the U.S. The capacity factor of geothermal generally ranges between 60-70 percent and can exceed 90 percent (Li et al. 2015); therefore, where the geothermal resource exists, it can provide a source of baseload electricity (DOE/EIA 2021a).

If geothermal is a reasonable alternative, the impacts to land use, visual, terrestrial ecology, cultural resources, human health, and noise would be similar to those for an NPP. The Programmatic Environmental Impact Statement for Geothermal Leasing in the Western United States provides an evaluation of the impacts of such facilities (BLM/USFS 2008). Impacts to water use and aquatic species would be less than for an NPP, based on roughly half the consumptive water use. Air quality impacts would be similar to an NPP for some geothermal plants. However, flash and dry steam power plants emit geothermal vapors to the atmosphere, potentially releasing hydrogen sulfide, carbon dioxide, mercury, arsenic, and boron. A geothermal plant would have minimal waste impacts during operations.

1.2.9 Biomass-Derived Fuels

Biomass energy can be generated from a wide variety of fuels, including municipal solid waste (MSW), refuse-derived fuel, landfill gas, urban wood wastes, forest residues, agricultural crop residues and wastes, and energy crops. Definitions of materials that qualify as biomass may vary in different States or regions depending on regulatory schemes or renewable portfolio standards. Biomass resources are widely available throughout the United States (see NRC 2013, Figure D.10-18). Biomass energy conversion is accomplished using a wide variety of technologies, some of which are similar in appearance and operation to fossil fuel plants, and include directly combusting biomass in a boiler or incinerator to produce steam, co-firing biomass along with fossil fuels (primarily coal) in boilers to produce steam, producing synthetic liquid fuels that are subsequently combusted, gasifying biomass to produce gaseous fuels that are subsequently combusted, and anaerobically digesting biomass to produce biogas. Synthetic fuel production, biomass gasification, and anaerobic digestion technologies have not been used to produce utility-scale electricity. Biogas is often consumed in combined heat and power plants with relatively small power generating capacities. To date, wood has been the most widely used biomass fuel for electricity generation, while coal-biomass co-firing and MSW combustion are also commercially feasible. While it is technically feasible to operate a biomass combustion plant on MSW or refuse-derived fuel, source material may not be reliable or consistent (NRC 2013).

MSW combustors use one of three types of technologies: mass burn, modular, or refuse-derived fuel. Mass burning is currently the method used most frequently in the United States and involves no (or little) sorting, shredding, or separation. Consequently, toxic or hazardous components present in the waste stream are combusted, and toxic constituents are exhausted to the air or become part of the resulting solid wastes. As of 2015, the United States had 71 operational waste-to energy plants, mostly located in Florida and the Northeast. These plants had a total generating capacity of 2,300 MW(e) (DOE/EIA 2016).

Environmental impacts to almost all resources from burning biomass such as MSW would be similar to those of a coal plant. Regarding waste, the burning of MSW would actually reduce the volume of waste requiring disposal.

Landfill gas is another potential source of biomass energy for electric power production. Landfills in which organic materials are disposed represent the largest source of methane in the United States. Landfill gas composition varies depending on the type of waste.

Collecting landfill gas is a relatively straightforward process that involves placing recovery wells and simple gas collection systems. Of the approximately 2,300 operating or recently closed landfills in the United States, 427 landfills are currently equipped with gas collection systems. In 2006, landfills produced enough gas to generate 10,000 GWh of electricity, equivalent to an average output of about 1,140 MW(e). An additional 560 landfills could be adapted to landfill gas-to-energy production. Because gas is produced continuously, landfill gas-to-energy plants can have capacity factors greater than 90 percent and can be relied upon as a source of baseload power.

The facilities to burn landfill gas would typically be built on landfill property, limiting impacts to land use. Other than emissions and waste, which would be like those of other combustion turbines, the environmental impacts of landfill gas plants would be minimal. However, such facilities are dependent on the location of an appropriate landfill and facilities are small in size. The average size of existing facilities is about 2.7 MW(e).

1.2.10 Fuel Cells

Fuel cells work without combustion and its associated environmental side effects. Power is produced electrochemically by passing a hydrogen-rich fuel over an anode, air over a cathode, and then separating the two by an electrolyte. The only byproducts are heat, water, and carbon dioxide. Hydrogen fuel can come from a variety of hydrocarbon resources by subjecting them to steam under pressure. Natural gas is typically used as the source of hydrogen (NRC and USACE 2016).

Phosphoric acid fuel cells are generally considered first-generation technology. Higher temperature, second-generation fuel cells achieve higher fuel-to-electricity and thermal efficiencies. The higher temperatures contribute to improved efficiencies and give the second-generation fuel cells the capability to generate steam for cogeneration and combined-cycle operations (NRC and USACE 2016).

During the past three decades, significant efforts have been made to develop more practical and affordable fuel cell designs for stationary power applications, but progress has been slow. The cost of fuel cell power systems must be reduced before they can be competitive with conventional technologies (DOE 2008). DOE has an initiative called the Solid State Energy Conversion Alliance with the goal of developing large (i.e., 250 MW or greater) fuel cell power systems, including those based on coal-derived fuels. Another goal of the Solid State Energy Conversion Alliance is to cut costs of electricity generated via fuel cells to $700 per kilowatt (electric) (DOE 2011). However, it is not clear whether DOE will achieve these goals and, if so, when the associated fuel cells might reach commercial operations.

At the present time, fuel cells are not economically or technologically competitive with NPPs or by other alternatives for baseload electricity generation. Future gains in cost competitiveness for fuel cells compared to other fuels are speculative.

1.2.11 Combination of Alternatives

NRC has assessed the environmental impacts of a combination of natural gas-fired combined-cycle power-generating units and renewable energy sources in 24 EISs since 2006 and determined in each that because of the intermittency of renewable energy sources, the design of such a system would necessarily require the natural gas-fired units to have a capacity similar to that of the proposed NPP project. While the inclusion of renewable sources would decrease the total emissions from the natural gas portion of this alternative, those sources would also introduce their own environmental impacts. These include land use impacts for solar and wind sources and emissions from sources such as biomass.

A combination of energy alternatives is developed by considering energy sources that are available in the region in which the proposed plant will be located. Considerations include the extent to which a given energy source is currently used in the region, along with projections of future growth from data sources such as DOE/EIA. The contribution of a viable energy source to the combination may be in the form of a range because of uncertainties regarding future growth. Energy efficiency and/or conservation can be considered part of the combination, in which case it can be considered in terms of a reduction in the amount of MW(e) that needs to be generated.

A combination of alternatives may include various storage technologies. These energy alternatives do not generate electricity; rather, they store energy during periods of low demand, and, during periods of high electricity demand, they return the stored energy to the grid. Examples of some storage technologies are included below.

Pumped storage, described in Section 1.2.6, Hydropower, may be an energy storage alternative that could be considered as part of a combination of alternatives. If the project would require the development of a new pumped storage facility, then the impacts of building and operating that new facility would be included in the impacts of the combination of alternatives.

A Compressed Air Energy Storage (CAES) plant consists of motor-driven air compressors that use low-cost, off-peak electricity to compress air into a suitable geological repository such as an underground salt cavern, a mine, or a porous rock formation. During periods of high electricity demand, the stored energy is recovered by releasing the compressed air through a combustion turbine to generate electricity (NPCC 2010). Two CAES plants are currently in operation. The first CAES plant, a 290-MW plant near Bremen, Germany, began operating in 1978. The second CAES plant, a 110-MW plant located in McIntosh, Alabama, has been operating since 1991. Both facilities use mined salt caverns for compressed air storage (Succar and Williams 2008). As of November 2021, there have not been any CAES projects developed in the United States since the 1990s.

Depending on the size of the project, a different type of energy storage (e.g., batteries) might be feasible. For battery storage it is important to consider both the power (MW) and energy (MWh) ratings of the system. For example, at the end of 2018, 869 MW of power capacity, representing 1,236 MWh of energy capacity, large-scale battery storage was in operation in the United States (DOE/EIA 2020b). This capacity equates to less than 1.5 hours of storage at full power output.

Flow cell technology is a type of battery storage having one or more chemical components dissolved in a liquid solution. A fuel cell consists of a negative electrode (or anode) and a positive electrode (or cathode) sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. Flow cells comprise electrochemical reduction and oxidization reactors occurring in liquid electrolytes containing metal ions. An advantage of this technology is that power capacity can be easily increased by using a larger storage reactor. At the end of 2016, flow batteries comprised less than 1% of the installed capacity of battery storage; however, various flow battery storage systems have been installed by utilities in Washington and California (DOE 2016/2017).

While flow cell cost has decreased by 60% and has increased in durability by a factor of 4 since 2006, the factors of cost, performance, and durability are still challenges. At the present time, flow cells are not economically or technologically competitive with NPPs or other alternatives for baseload electricity generation (DOE 2016/2017).

Cooling Water System Design Mitigation for Large Light Water Reactors

The environmental review may also consider a variety of heat-dissipation system and circulating-water system (CWS) alternatives, particularly for LLWRs. While other heat-dissipation systems and water systems are part of an NPP, the largest and most capable of causing environmental impacts is the CWS that cools and condenses the steam for the turbine generator. Other water systems (e.g., the service-water system) are much smaller and therefore use less water than the CWS. Most environmental reviews only consider alternative heat-dissipation intake and discharge systems for the CWS (NRC and USACE 2016).

1.3 Heat Dissipation Mitigation Alternatives

1.3.1 Wet Mechanical Draft Cooling Towers

Wet mechanical draft cooling towers use fans to force air through the stream of cooling water resulting in latent and sensible heat loss. The cooling towers rely primarily on evaporation to dissipate the heat, resulting in consumptive water use.[2] For example, the proposed Bell Bend plant, with a power rating of 1,600 MW(e), would have had a consumptive water use of 15,880 gallons per minute (gpm) from evaporation and drift, or roughly 10 gpm per MW(e). The associated intake flow would have been about 23,800 gpm (or about 15 gpm/MW(e)), and the discharge (blowdown) would have been about 8,000 gpm (NRC and USACE 2016). The operation of the intake and discharge can cause noticeable effects on aquatic biota. Mechanical draft cooling towers are not as tall as other structures on site, such as the reactor building. As a result, these towers do not contribute to aesthetic or visual impacts, nor are they likely to add significantly to incidents of avian or bat collisions with site structures. The fans required for mechanical draft would consume some of the proposed plant’s power.

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[2] Water use is similar for both mechanical draft and natural draft cooling towers.

1.3.2 Natural Draft Cooling Towers

A natural draft cooling tower operates on the same heat-dissipation principles as a mechanical draft (wet) cooling tower with the exception that the movement of air up through the tower is induced without the use of a mechanical fan. Instead, the tower draft is induced by the buoyancy of the lower density, heated air that rises within the tower and thereby draws cooler air in at the base of tower. Because operating the fan in a mechanical draft tower requires power (less than 1 percent of plant power [EPA 2001]), the natural draft tower will be marginally more power efficient. Land use required for a natural draft tower is somewhat less than a mechanical draft tower system and consumptive water use is similar. To generate adequate air flow, natural draft cooling towers are generally several hundred feet tall, much taller than a mechanical draft tower. The height of a natural draft tower reduces the potential for local impacts from drift contamination and fogging/icing relative to a mechanical draft tower. However, the greater height (600 feet or more) increases the visibility of the tower and the visibility and shading of the associated plume. The greater visibility needs to be considered in the National Historic Preservation Act (54 U.S.C. § 300101 et seq.) Section 106 consultation and in visual impacts. In addition, the greater height of natural draft cooling towers will generally increase the likelihood of bird and bat collision impacts. Because there is no fan, noise from a natural draft tower may be lower than from a mechanical draft tower.

1.3.3 Once-Through Cooling

Once-through cooling systems withdraw water from the source water body and return virtually the same volume of water at an elevated temperature to the receiving water body. Typically, the source water body and the receiving water body are the same, and the intake and discharge structures are separated to limit recirculation. While there is essentially no consumptive use of water in a once-through heat-dissipation system, the elevated temperature of the receiving water body would result in some induced evaporative loss that decreases the net water supply. The elevated temperature also can adversely affect the biota of the receiving water body. The large intake flows would result in impingement and entrainment losses and the thermal impacts on aquatic biota during low-flow conditions may be significant. For example, Millstone Units 2 and 3, with a combined output of 2,034 MW(e), has a nominal intake flow of 1,460,000 gpm, or about 718 gpm/MW(e) (NRC 2005). Compared to Bell Bend, the Millstone intake flow is almost 50 times as high per MW(e). Based on recent changes to implementation plans to meet Section 316(b) of the Clean Water Act, once-through cooling systems for new nuclear reactors are unlikely to be permitted in the future, except in rare and unique situations.

1.3.4 Cooling Pond

Cooling ponds are man-made bodies of water used in closed-cycle cooling systems in place of cooling towers. Sensible heat is transferred to the atmosphere and to the ground, and latent heat transfer occurs through evaporation from the pond surface. Studies performed by one applicant determined the size pond needed for a 1,300 MW plant to be 2,470 acres (PPL Bell Bend 2013). The pond would eliminate substantially greater areas of wetlands, terrestrial habitat, and natural surface-water habitat than would other CWS alternatives. Because cooling ponds are open features, their performance may depend on unique characteristics, such as site ground conditions (ponds may need to be lined), pond volume and depth, wind speeds, and solar load. However, because these ponds are man-made and are not stocked with fish, cooling ponds avoid the issues of impingement and entrainment.

1.3.5 Spray Pond

Spray ponds are cooling ponds that use water spray to enhance heat transfer, primarily by increasing evaporation. Like wet cooling towers, spray ponds require makeup water from an external source and occasionally discharge water to a receiving water body to control the concentration of dissolved solids. Like cooling ponds, the performance of spray ponds depends on various land use and climactic conditions.

Land use for a spray pond cooling system is expected to be significantly larger than either mechanical or natural draft cooling tower systems. Because a spray pond system would rely primarily on evaporative cooling, water use is expected to be similar to cooling towers. Drift and plume impacts (fogging/icing, visibility) would be comparable to a mechanical draft tower, although potentially more localized because emissions would be closer to the ground surface. These localized impacts could be of concern depending on the location of the spray ponds. In addition to evaporation, heat transfer from the spray ponds to the atmosphere occurs through black-body radiation and conduction. With the introduction of sprays, terrestrial and aquatic habitat adjacent to the pond could be exposed to drift from spray operations. However, because these ponds are man-made and are not stocked with fish, cooling ponds avoid the issues of impingement and entrainment.

1.3.6 Dry Cooling Towers

A heat-dissipation system using dry cooling relies on sensible heat exchange to the ambient air without using water for evaporative cooling. In one possible configuration (indirect dry cooling), cooling water circulating in the condenser would be sent to a dry cooling tower where fans are used to induce a draft across a heat exchanger. Alternatively, the turbine exhaust steam could be cooled directly in an air-cooled condenser, although this is considered an unlikely cooling system for an NPP (EPRI 2012). No existing U.S. NPP uses a dry cooling system.

By eliminating water use for cooling, a dry cooling system would virtually eliminate the impacts associated with makeup water withdrawal and blowdown discharge (it is assumed that impacts of radiological waste discharge to the river would be unchanged). A dry cooling system is less efficient than a wet system because the theoretical approach temperature is limited to the dry bulb temperature instead of the lower wet bulb temperature. Relative to a wet mechanical draft system, this may result in a loss of steam turbine efficiency (particularly during high ambient temperature conditions), a larger cooling system, and more energy use by the dry cooling fans. Estimates of the total average annual energy penalty for an NPP using dry cooling towers (vs. wet cooling towers) range from about 3 to 7 percent of plant output (30 to 70 MW(e) for a 1000 MW(e) reference plant) (EPA 2001; EPRI 2012). The EPA (2001) states that dry cooling towers generally occupy three to four times the area of wet cooling towers providing comparable cooling capacity. Noise from the larger/more numerous dry cooling fans is expected to be greater than a wet natural draft cooling tower system. In addition, the loss of generation efficiency translates into increased impacts on the fuel cycle. Dry cooling would eliminate any impacts from a cooling-tower plume, including drift contamination, fogging/icing, and visibility.

1.3.7 Combination Wet/Dry Hybrid Cooling-Tower System

A heat-dissipation system using wet/dry cooling towers comprises both wet and dry cooling tower sections. Depending on the ambient air temperature, relative humidity and the system design, the system may be operated to dissipate heat entirely in the wet section, entirely in the dry section, or using the combined wet and dry sections. Overall water withdrawal and consumptive use depend on the fraction of time during plant operation that the dry tower section is operating. The availability of evaporative cooling in the wet section reduces the average annual energy penalty of the wet/dry cooling system when compared to a dry cooling system.

Combination wet/dry hybrid cooling towers have never been used to cool large-scale nuclear or fossil fuel facilities.[3] A mechanical draft wet/dry hybrid cooling-tower system would reduce the average consumption of cooling water, often with the added benefit of reducing plume visibility. Water used to cool the turbine generators generally passes first through the dry portion of the cooling tower where heat is removed by drawing air at ambient temperature over tubes through which the water is moving. Cooling water leaving the dry portion of the tower then passes through the wet tower where the water is sprayed into a moving air stream and additional heat is removed through evaporation and sensible heat transfer. When ambient air temperatures are low, the dry portion of these cooling towers may be sufficient to meet cooling needs. During hot, dry summer months, a hybrid system still would rely on the wet portion of the system and, therefore, would have a reduced benefit at the same time that consumptive-use concerns are highest. The use of the dry portion of the system would result in a loss in generating efficiency that would translate into increased impacts on the fuel cycle. While such hybrid cooling technology may be feasible, it still poses several significant technical challenges for its installation and operation.

1.3.8 Mechanical Draft with Plume Abatement

Adding additional heat to a saturated cooling tower exhaust, without adding additional water, would result in sub-saturated water vapor. Sub-saturated water vapor reduces the potential for a visible plume. The concept behind a mechanical draft cooling tower with plume abatement is similar to the wet/dry hybrid cooling system described above with the design parameters focused on reducing the visual plume. Such designs also may result in slightly less consumptive water use than mechanical draft cooling towers without plume abatement. These towers often have a larger footprint and require additional energy to operate, resulting in a net loss of energy available to meet the demand for power.

1.4 Circulating Water System Mitigation Alternatives

Circulating water system mitigation alternatives for a given proposed project may include alternatives modifying the intake or discharge locations or systems. Because the circulating water system and associated potential alternative locations or technologies are unknown until considering a specific license application in a given geographic area, they must be addressed

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[3] If built, North Anna Unit 3 would have a hybrid wet/dry cooling system. This design was required by the Commonwealth of Virginia to address consumptive water use during drought conditions.

during project-specific National Environmental Policy Act of 1969 reviews and cannot be analyzed generically in this white paper.

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Appendix A –Summary of Alternative Energy Technologies and Impacts as Compared to Nuclear

	Land Use	Visual	Air Quality	Water	Terrestrial	Aquatic	Cultural	Human Health	Noise	Waste	Accidents	Environmental Justice (EJ)
Coal	NUREG-1437 (NRC 1996) estimates 1700 acres for a 1000 MW(e) plant, or 1.7 acres/MW(e). An additional 22,000 acres, or 22 acres/MW(e), could be impacted for mining and disposal of waste.	Similar to a nuclear power plant (NPP) at the site. Additional impacts at the location of mining.	Regulated air emissions of various pollutants much greater than NPPs. Significant CO_2 emissions that contribute to climate change.	Similar to an NPP at the site. As an example, the proposed Bell Bend plant would have consumed (evaporated) around 17,000 gpm for a net electrical output of 1600 MW(e), or about 11 gpm/MW(e).	Greater than an NPP because of land use at the site and at the location of mining.	Similar to an NPP at the site. As an example, the proposed Bell Bend plant would have withdrawn around 25,730 gpm for a net electrical output of 1600 MW(e). The plant would have discharged about 7930 gpm. Potential for additional impacts at the location of mining.	Potentially greater than an NPP because of land use at the site and at the location of mining.	Greater impacts than an NPP because of air emissions.	Greater impacts than an NPP because of coal handling equipment. If coal and other materials are transported to the site by rail, that will add to the noise impacts.	Much greater impacts than an NPP, although some waste products (e.g., fly ash) might be put to other uses.	Coal plants have no real equivalent to severe accidents. However, some coal plants have had offsite consequences from failures related to disposal of waste.	Any impacts to minority and low-income populations would generally be similar to those of an NPP.
Combined Cycle Natural Gas (NGCC)	NUREG-1437 estimates 110 acres for a 1000 MW(e) plant, or 0.11 acres/MW(e). An additional 3600 acres, or 3.6 acres/MW(e), would be required for wells, collection stations, and pipelines.	Similar to an NPP at the site. Additional impacts at the location of wells, collection stations, and pipelines.	Regulated air emissions of various pollutants greater than NPPs. Significant CO_2 emissions that contribute to climate change.	Roughly half the consumptive water use of an NPP because of higher thermal efficiency.	Similar to an NPP at the site.	Less than an NPP at the site because of lower consumptive water use. Potential for additional impacts at the location of wells, collection stations, and pipelines.	Similar to an NPP at the site. Potential for additional impacts at the location of wells, collection stations, and pipelines.	Similar to an NPP at the site.	Similar to an NPP at the site.	Similar to an NPP at the site.	Natural gas plants have no real equivalent to severe accidents.	Similar to an NPP at the site.
Oil	NUREG-1437 estimates 120 acres for a 1000 MW(e) plant, or	Similar to an NPP at the site. Additional impacts at the	Similar to coal. Regulated air emissions of various pollutants much	Similar to coal and NPPs.	Similar to an NPP at the site.	Similar to coal and NPPs.	Similar to an NPP at the site. Potential for additional impacts at the	Similar to coal. Greater impacts than an NPP because of air emissions.	Similar to an NPP at the site.	Similar to coal.[4] Much greater impacts than an NPP.	Oil plants have no real equivalent to severe accidents.	Similar to an NPP at the site.

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[4] Previous EISs have not discussed this topic because DOE is projecting no new oil plants and an ongoing decline in existing oil plants.

	Land Use	Visual	Air Quality	Water	Terrestrial	Aquatic	Cultural	Human Health	Noise	Waste	Accidents	Environmental Justice (EJ)
	0.12 acres/MW(e). Additional land would be required for pipelines.	location of pipelines.	greater than NPPs. Significant CO_2 emissions that contribute to climate change.				location of pipelines.					
Land-Based Wind	A wind farm requires roughly 60 acres/MW of installed capacity, although most of this land could be used for other compatible functions, such as farming. Because the capacity factor of wind is 28–35 percent (as opposed to 90 percent for NPPs), to get the same average energy output, the capacity of a wind farm would need to be roughly 3 times that of an NPP. Using a 30 percent capacity factor, a wind farm would need an installed capacity of 3000 MW(e) to match the energy output of a 1000 MW(e) NPP with a capacity factor of 90 percent. Such a wind farm would cover roughly 180,000 acres.	Impacts are greater than NPPs. Visual impacts of land clearing (if required) can be very significant. Impacts of the operating turbines to a view shed can also be very significant.	Depending on the amount of land that needs to be cleared, there can be some air quality impacts from dust and equipment exhaust during construction. These impacts would typically be addressed through best management practices (BMPs).	Similar to NPPs. Depending on the amount of land that needs to be cleared, there will be erosion and sedimentation that would adversely affect water resources. These impacts would typically be addressed through BMPs.	Impacts are greater than NPPs. The impacts to terrestrial resources will be greatest if natural habitats must be cleared for the turbines. Lesser impacts would occur if the turbines are built on farmland. During operations, bird collisions with the turbines can affect such species, especially if the wind turbines are located in or near migration areas and nesting locations.	Similar to NPPs during construction. Depending on the amount of land that needs to be cleared, there will be erosion and sedimentation that would adversely affect aquatic resources. These impacts would typically be addressed through BMPs. Much less than NPPs during operations because water is not used.	Impacts are greater than NPPs. Depending on the amount of land that needs to be cleared, there could be significant construction impacts to historic and cultural resources. Visual impacts to resources from operating wind turbines can also be significant.	Similar to NPPs. Human health, except for a potential small number of occupational injuries, would not be affected by construction and operations.	Noise can be an issue for people living or recreating near a wind farm. Noise impacts would likely be similar to those of an NPP, although the affected area is much larger.	Similar to NPPs during construction. Depending on the amount of land that needs to be cleared, there could be a significant amount of plant debris that requires disposal. However, impacts of such disposal are expected to be minor. Waste issues from operations would be less than NPPs.	Onshore wind farms have no real equivalent to severe accidents.	Any impacts to minority and low-income populations would occur only if such populations were in close proximity to the wind farm, subjecting such populations to visual and noise impacts.
Offshore Wind	Generally minimal impacts to land use related to onshore power transmission lines and equipment. Fewer impacts than NPPs.	Impacts of the operating turbines to a coastal view shed can be very significant. Impacts would be similar to, or greater than,	Minor air quality impacts from equipment exhaust during construction. These would typically be addressed through BMPs. Impacts would	In-water work and discharges from work vessels may have localized impacts on water quality. No water use from operations.	Generally minimal impacts to terrestrial resources related to onshore power transmission lines and equipment. During	Using the Cape Wind project as an example, construction could have a moderate impact on some aquatic species. Operations would have a	Impacts to historic and cultural resources during construction will generally be minor. Visual impacts to resources from operating wind	Similar to NPPs. Human health, except for a potential small number of occupational injuries, would not be affected by construction and operations.	Noise impacts will be negligible because of the distance offshore of the turbines. Fewer impacts than NPPs.	There would be negligible waste impacts for offshore wind. Fewer impacts than NPPs.	Offshore wind farms have no real equivalent to severe accidents.	Any impacts to minority and low-income populations would occur only if such populations were in close proximity to the shore near the wind farm,

	Land Use	Visual	Air Quality	Water	Terrestrial	Aquatic	Cultural	Human Health	Noise	Waste	Accidents	Environmental Justice (EJ)
		NPPs, depending on the circumstances.	be similar to NPPs.	Fewer impacts than NPPs.	operations, bird collisions with the turbines can affect such species, especially if the wind turbines are located in or near migration areas. Fewer impacts than NPPs.	minor impact. The Cape Wind offshore wind farm would have occupied 16,000 acres for 130 turbines with a rated output of 468 MW(e). That equates to 34 acres/MW(e). Offshore wind farms operate at a capacity factor of roughly 40 percent. Impacts would be similar to, or less than, NPPs, depending on the circumstances.	turbines may be significant. Impacts relative to an NPP would be site-specific.					subjecting such populations to visual impacts.
Solar Photovoltaic (PV)	A solar PV facility requires over 5 acres/MW(e) of installed capacity. In addition, the capacity factor for solar PV is roughly 25 percent on average.[5] To generate the same amount of energy as a 1000 MW(e) NPP with a capacity factor of 90 percent, the solar facility would need an installed capacity of 3600 MW(e), covering an area of about 18,000 acres. None of the land can be used for other purposes.	Impacts are greater than NPPs. Visual impacts of land clearing are very significant.	Similar to NPPs. Land clearing will cause some air quality impacts from dust and equipment exhaust during construction. These impacts would typically be addressed through BMPs.	Depending on the amount of land that needs be cleared, there will be erosion and sedimentation that would adversely affect water resources. These impacts would typically be addressed through BMPs. Fewer impacts than NPPs because of no water use for operations.	Impacts are greater than NPPs. If previously cleared land is used, the impacts to terrestrial resources will still be noticeable. If the affected land needs to be cleared of natural vegetation, the impacts to terrestrial resources will be significant.	Depending on the amount of land that needs to be cleared, there will be erosion and sedimentation that would adversely affect aquatic resources. These impacts would typically be addressed through BMPs. Fewer impacts than NPPs because of no water use for operations.	Impacts are greater than NPPs. Depending on the amount of land that needs to be cleared, there could be significant construction impacts to historic and cultural resources. Visual impacts to resources from the operating solar array may also be noticeable.	Similar to NPPs. Human health, except for a potential small number of occupational injuries, would not be affected by construction and operations.	Similar to NPPs. Noise can be an issue for people living or recreating near a solar array during construction. Noise is not an issue during operations.	Similar to NPPs during construction. Depending on the amount of land that needs to be cleared, there could be a significant amount of plant debris that requires disposal. However, impacts of such disposal are expected to be minor. Fewer waste impacts than NPPs from operations.	Solar arrays have no real equivalent to severe accidents.	Any impacts to minority and low-income populations would occur only if such populations were in close proximity to the solar array, subjecting such populations to visual impacts.

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[5] See https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b.

	Land Use	Visual	Air Quality	Water	Terrestrial	Aquatic	Cultural	Human Health	Noise	Waste	Accidents	Environmental Justice (EJ)
Concentrating Solar	Concentrating solar power (CSP) facilities average more than 7.5 acres/MW(e).[6] Capacity factors for CSP vary widely, ranging from roughly 30 percent without thermal storage to over 60 percent in some cases with storage. Using the higher number of 60 percent, a CSP plant would need an installed capacity of 1500 MW(e) to match the energy output of a 1000 MW(e) NPP with a capacity factor of 90 percent. Such a CSP plant would cover roughly 11,250 acres.	Impacts are greater than NPPs and similar to solar PV. Less land is required than PV. But a CSP plant will include large plant buildings and, in some cases, a tall tower.	Similar to NPPs. Land clearing will cause some air quality impacts from dust and equipment exhaust during construction. These impacts would typically be addressed through BMPs.	Depending on the amount of land that needs to be cleared, there will be erosion and sedimentation that would adversely affect water resources. These impacts would typically be addressed through BMPs. Water use during operations would be similar to an NPP using a similar cooling system	Impacts are greater than NPPs. If previously cleared land is used, the impacts to terrestrial resources will still be noticeable. If the affected land needs to be cleared of natural vegetation, the impacts to terrestrial resources will be significant. In addition, certain CSP plant designs will impact avian species that fly through the concentrated beams of sunlight.	Similar to an NPP using the same type of cooling system.	Impacts are greater than NPPs. Depending on the amount of land that needs to be cleared, there could be significant construction impacts to historic and cultural resources. Visual impacts to resources from the operating CSP plant may also be noticeable.	Similar to NPPs. Human health, except for a potential small number of occupational injuries, would not be affected by construction and operations.	Similar to NPPs. Noise can be an issue for people living or recreating near a solar array during construction. Noise is not an issue during operations.	Similar to NPPs during construction. Depending on the amount of land that needs to be cleared, there could be a significant amount of plant debris that requires disposal. However, impacts of such disposal are expected to be minor. Fewer waste impacts than NPPs from operations.	CSP plants have no real equivalent to severe accidents.	Any impacts to minority and low-income populations would occur if such populations were in close proximity to the CSP plant, subjecting such populations to visual impacts. In addition, there could be impacts associated with water use, similar to potential impacts of an NPP.
Hydro	A conventional hydroelectric facility rated at 1000 MW(e) would require flooding roughly 1600 mi^2 of land. Based on current projections, the construction of such a facility in the U.S. in the future is unlikely.	Greater impacts than NPPs. Significant impacts as a large land area is converted to a reservoir.	Similar to NPPs. Land clearing will cause some air quality impacts from dust and equipment exhaust during construction. These impacts would typically be addressed through BMPs.	Greater impacts than NPPs. The hydroelectric facility will change the flow characteristics in the river downstream of the dam to meet the needs of the facility.	Greater impacts than NPPs. Significant impacts as a large land area is converted to a reservoir.	Greater impacts than NPPs. Significant impacts as a riverine environment is converted to a reservoir.	Greater impacts than NPPs. Significant impacts as a large land area is converted to a reservoir.	Similar to NPPs. Human health, except for a potential small number of occupational injuries, would not be affected by construction and operations.	Similar to NPPs. Noise can be an issue for people living or recreating near the reservoir and dam during construction. Noise is not an issue during operations.	Greater than NPPs during construction. During land clearing, there could be a significant amount of plant debris that requires disposal. However, impacts of such disposal are expected to be minor. Less waste impacts than NPPs from operations.	In the unlikely event of a dam failure, there would be devastating damage downstream.	The most likely impacts to minority and low-income populations would occur if such populations were forced to relocate from the location of the reservoir. The change in downstream flows might also affect such populations.

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[6] See "Land-Use Requirements for Solar Power Plants in the United States," NREL, June 2013.

	Land Use	Visual	Air Quality	Water	Terrestrial	Aquatic	Cultural	Human Health	Noise	Waste	Accidents	Environmental Justice (EJ)
Wave	Similar to offshore wind. Generally minimal impacts to land use related to onshore power transmission lines and equipment. Fewer impacts than NPPs.	Fewer impacts than NPPs. None except for possible minor impacts related to onshore power transmission lines and equipment.	Similar to NPPs. Minor air quality impacts from equipment exhaust during construction. These would typically be addressed through BMPs.	Fewer impacts than NPPs. In-water work and discharges from work vessels may have localized impacts on water quality.	Fewer impacts than NPPs. Similar to offshore wind. Generally minimal impacts to terrestrial ecology related to onshore power transmission lines and equipment.	Likely minor, although there is very limited data. Fewer impacts than NPPs.	Fewer impacts than NPPs. None except for possible minor impacts related to onshore power transmission lines and equipment.	Similar to NPPs. Human health, except for a potential small number of occupational injuries, would not be affected by construction and operations.	Fewer impacts than NPPs. Noise impacts will be negligible.	Fewer impacts than NPPs. Waste impacts will be negligible.	Wave generators have no real equivalent to severe accidents.	Impacts to minority and low-income populations are unlikely.
Geothermal[7]	Similar to an NPP at the site. The typical acreage of disturbance in a geothermal resource development phase is 53 to 367 acres (BLM/NFS 2008).	Similar to an NPP at the site because of the necessary plant structures.	Similar to an NPP at the site for some geothermal plants. However, flash and dry steam power plants emit geothermal vapors to the atmosphere, potentially releasing hydrogen sulfide, carbon dioxide, mercury, arsenic, and boron (BLM/NFS 2008).	A geothermal plant will use about half as much water as a typical NPP (and about the same amount as an NGCC plant). Therefore, impacts to water use and quality would be less than an NPP.	Similar to an NPP at the site because land use is similar.	Somewhat less than an NPP at the site and about the same as an NGCC based on water use.	Similar to an NPP at the site because land use and visual impacts are similar.	Similar to NPPs. Human health, except for a potential small number of occupational injuries, would not be affected by construction and operations.	Similar to an NPP at the site. Noise is generated both during construction and operations (BLM/NFS 2008).	Fewer impacts than NPPs. Waste impacts would be minimal for a geothermal plant.	Geothermal plants have no real equivalent to severe accidents.	Any impacts to minority and low-income populations would occur if such populations were in close proximity to the geothermal plant, subjecting such populations to visual and noise impacts. In addition, there could be impacts associated with water use, similar to potential impacts of an NPP.
Biomass	Similar to an NPP at the site. Biomass plants require land for receiving, sorting, and storing the material to be burned, as well as land for the power plant.	Similar to an NPP at the site because of the necessary plant structures.	Similar to a coal plant, and much greater than an NPP because of the products of combustion.	Similar to an NPP at the site because of the need for cooling water for the steam plant.	Similar to an NPP at the site because land use is similar.	Similar to an NPP at the site because water use is similar.	Similar to an NPP at the site because land use and visual impacts are similar.	Greater impacts than an NPP because of air emissions.	Greater impacts than an NPP because of materials handling equipment. Transportation of materials to the site will likely add to the noise impacts.	Similar to NPPs. While there will be wastes from combustion, burning the biomass materials reduces the amount of waste that would otherwise have to be disposed in landfills or similar.	Biomass plants have no real equivalent to severe accidents.	Any impacts to minority and low-income populations would occur if such populations were in close proximity to the biomass plant, subjecting such populations to air quality, visual and noise impacts. In addition, there

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[7] Most geothermal resources exist in portions of the western United States and Hawaii (NRC 2013). Therefore, the applicability of this alternative to a given project is geographically limited.

	Land Use	Visual	Air Quality	Water	Terrestrial	Aquatic	Cultural	Human Health	Noise	Waste	Accidents	Environmental Justice (EJ)
												could be impacts associated with water use, similar to potential impacts of an NPP.
Fuel Cells	Less than an NPP. An example 1 MW fuel cell unit would occupy about 800 ft^2 (Hydrogenics 2020). This would equate to less than 20 acres for 1000 MW(e). Additional land may be required for a pipeline for delivery of the fuel to the site. A 1 MW(e) fuel cell would consume on the order of 26,000 ft^3/hr of natural gas. Fuel cell installations are typically small. Large installations (> 1 MW) average about 2.5 MW (DOE/EIA 2018).	Fewer impacts than an NPP because of the smaller footprint and lack of tall structures.	Similar to an NPP because there are essentially no emissions.	Fewer impacts than NPPs because no water is required for operation of a fuel cell.	Fewer impacts than an NPP because of the smaller footprint.	Fewer impacts than NPPs because no water is required for operation of a fuel cell.	Fewer impacts than an NPP because of the smaller footprint.	Similar to an NPP at the site. Human health, except for a potential small number of occupational injuries, would not be affected by construction and operations.	Fewer impacts than an NPP because there are few moving parts.	Fewer impacts than NPPs because the byproduct of operations is water.	Fuel cells have no real equivalent to severe accidents.	Any impacts to minority and low-income populations would likely be less than those of NPPs.