Electric Power Generation, Transmission and Distribution Industry Practices and Environmental Characterization

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Operational and decommissioning practices in industrial sectors and their associated firms can ultimately affect the ability of individual firms to responsibly minimize their impact on human health and the environment. To consider the potential for releases as part of its decision making, EPA prepared this high-level review of industry practices and the environmental profile of the Electric Power Generation, Transmission and Distribution industry, which includes a summary of relevant operational and decommissioning materials and wastes.

This document endeavors to review how current electrical power generation, transmission and distribution industry practices have affected the non-permitted releases of hazardous substances into the environment. It also discusses how the nature and frequency of releases and other impacts may have changed over time. As documented in the 2010 Advance Notice of Potential Rulemaking (ANPRM)[1], the types of hazardous substances that have been released from facilities in the Electric Power Generation, Transmission and Distribution industry include hydrogen fluoride; vanadium, zinc, copper, and lead compounds; ammonia; and arsenic, cobalt, barium, cadmium, and selenium compounds. Coal combustion residuals frequently contain arsenic, selenium, mercury, and other toxic metals. Other substances beyond those listed here may also have been released from facilities in the industry. Additional current information on releases for this sector is also available on the EPA "Smart Sectors" websites[2], and the electrical utility industry sections (pages 97 through 102) of the Toxic Release Inventory (TRI) National Analysis for 2017[3].

Each of the sections that follow describes operating and decommissioning electrical power generation, transmission and distribution industry waste management methods in the United States and provides a brief overview description of how they are implemented.

A. Generation - Electric generating plants convert mechanical, chemical, and/or fission energy into electric energy. Within this population of electric generating plants, there are different types of processes employed to produce electricity (e.g., coal-fired power plants, wind turbines). Further information on the environmental performance characteristics of this industry are included in the previously published Advanced Notice of Potential Rulemaking[4].

   Waste from electricity generation arises at each step of the fuel cycle: mining, fuel fabrication or preparation, power production operations, and decommissioning. This characterization review concerns only the operations and decommissioning steps of direct relevance to the Electrical Power Generation, Transmission and Distribution Industry. Operation of any power plant requires use of a variety of nonhazardous materials, including paper, cardboard, wood, aluminum, containers, packaging materials, office waste, municipal trash etc. Potentially hazardous materials are also frequently used. These materials can include sandblast media, fuels, paints, spent vehicle and

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[1] https://www.federalregister.gov/documents/2010/01/06/E9-31399/identification-of-additional-classes-of-facilities-for-development-of-financial-responsibility
[2] https://www.epa.gov/smartsectors/utilities-and-power-generation-sector-information, https://cfpub.epa.gov/wizards/smartsectors/utilities/#Chart
[3] https://www.epa.gov/trinationalanalysis/comparing-industry-sectors
[4] https://www.federalregister.gov/documents/2010/01/06/E9-31399/identification-of-additional-classes-of-facilities-for-development-of-financial-responsibility

equipment fluids (e.g., lubricating oils, hydraulic fluids, battery electrolytes, glycol coolants) among others. Hazardous materials may include, but are not limited to, asbestos or mercury containing materials, compressed gases used for welding and cutting, dielectric fluids, boiler bottom ash, and oils. Process fluids can be either hazardous or non-hazardous, and can include oily water, spent solvents, chemical cleaning rinses, cooling water, wash and makeup water, sump and floor discharges, oily water seperator fluids, boiler blowdown, and water from surface impoundments. Other materials beyond those listed here may be used in the operation of power plants. As an example, site specific references[5] show the primary waste streams generated during Morrow Bay facility operations, including a description of each waste, its origin and composition, estimated amount, frequency of generation, and waste management methods. The 2017 Oak Ridge National Laboratory Lab report on Solid Waste from the Operation and Decommissioning of Power Plants[6] Tables 1.2 and 1.3 reproduced below also present an overview of waste streams from a variety of power plant types.

Table 1.2. Overview of Solid Waste Streams from Fossil-Fuel and Nuclear Plants

	Coal	Natural Gas & Oil	Nuclear
Unique Fuel, Waste, Recycling, and Storage Issues			
Waste from Fuel Consumption	Coal combustion byproducts (fly ash, bottom ash, slag, scrubber slurries), limited radioactive coal ash removed at decommissioning	Limited radioactive sludge removed at decommissioning	Nuclear waste (high- and low-level nuclear waste)
Waste Storage/Management	Wet ponds and dry impoundments		Spent fuel pools and dry casks
Beneficial Uses of Waste/Recycling	Gypsum board, concrete blocks, highway construction, road embankments, ice traction control, blasting materials, grit on roof shingles		While currently prohibited in the United States, other countries recycle spent nuclear fuel
On-Site Fuel Storage/Management	Aboveground coal piles	Above and underground gas & oil tanks and pipes	Nuclear fuel rods
Common Decommissioning Waste Streams			
Powerhouse Equipment	Generators, turbines, boilers, precipitators, pumps	Generators, turbines, boilers, precipitators, pumps	Generators, pumps
Structures	Buildings, pads and cooling towers	Buildings, pads and cooling towers	Buildings, pads and cooling towers
T&D Equipment	Cables, Wiring, Transmission Towers, Poles, Underground Cables	Cables, Wiring, Transmission Towers, Poles	Cables, Wiring, Transmission Towers, Poles
Power Electronics	Inverters, transformers and other power electronics	Inverters, transformers and other power electronics	Inverters, transformers and other power electronics
Transport Infrastructure	Railway spurs and access roads	Pipelines and access roads	Access roads
Recyclable/Salvageable Decom. Wastes	Steel, copper, brick, concrete	Steel, copper, brick, concrete	Steel, copper, brick, concrete

[5] Morro Bay Modernization & Replacement Power Plant project 10/23/2000 California Energy Commission docket 00-AFC-12C
https://www.energy.ca.gov/sitingcases/morrobay/documents/applicants_files/AFC_vol_1b/app_1b_f614_Waste Management.pdf

[6] ORNL/SPR-2017/774 of 5 Jan 2017. Solid Waste from the operation and Decommissioning of Power Plants

Table 1.3. Overview of Solid Waste Streams from Renewable Electricity Plants

	Hydropower	Wind	Solar Photovoltaics
Unique Fuel, Waste, Recycling, and Storage Issues			
Waste from Fuel Consumption	--	--	--
Waste Storage/Management	--	--	--
Beneficial Uses of Waste/Recycling	--	--	
On-Site Fuel Storage	Water reservoirs with attendant siltation issues	--	--
Common Decommissioning Waste Streams			
Powerhouse Equipment	Generators, hydro-turbines, pumps	Towers, blades, gearbox, generator, nacelle	Solar photovoltaic panels
Structures	Dams and buildings	Poles and blades	Steel frames
T&D Equipment	Cables and wiring	Cables and wiring	Cables and wiring
Power Electronics	Inverters, transformers and other power electronics	Inverters, transformers and other power electronics	Inverters, transformers and other power electronics
Transport Infrastructure	Access roads	Access roads	Access roads
Recyclable/Salvageable Decom. Wastes	Steel, concrete, copper	Steel, copper, fiberglass	Recycling of steel, glass, silicon wafers, and rare earth elements

Industry practices in certain subsectors, the Fossil Fuel Generation, Transmission and Distribution of the Electric Power Generation, Transmission and Distribution industry use more hazardous substances and/or generate larger volumes of hazardous waste. Several generation subsectors use and generate lower amounts of hazardous substances or wastes, including Hydroelectric, Nuclear, Solar, Wind, Geothermal and Tidal. Unique characteristics within the sub sectors are covered below.

i. Hydroelectric power generation – There are two types of hydroelectric power projects: conventional and pumped storage. In a conventional hydroelectric facility, water passes from the intake and out the outflow one time. In a pumped storage facility, water may pass through the turbine multiple times. The operation of a hydropower project, like any power plant, may generate solid and industrial wastes.

The decommissioning of a hydroelectric power plant may be a significant source for waste generation. The average US hydroelectric facility has been operating for 64 years. The 50 oldest electric generating plants in the United States are all hydroelectric generators; each in service since 1908[7], suggesting an increase in the decommissioning activity that may take place in the coming years.

[7] Hydroelectric generators are among the United States' oldest power plants - accessed 10 Jun 2019 at https://www.eia.gov/todayinenergy/detail.php?id=30312

Hydroelectric power generation decommissioning includes waste management of any reservoir sediments, especially where power plant placement is downstream from significant industrial or natural environmental hazard sources. For example, the 2005 Superfund[8] dismantling of the Milltown hydroelectric plant on the Clark Fork River in Montana included 6.6M yd^3 of silt laden with arsenic, copper, zinc and other heavy metals[9]. Upstream mining activities created this deposition of hazardous constituents, not a normal operation of the generation facility.

In a potentially more typical example, the 2005 removal of the Fort Halifax[10] plant on the Sebasticook River, in Kennebec County Maine, found that accumulated impoundment sediments exposed in the floodplain would be subject to inundation and potential erosion. However, the Final Environmental Assessment concluded that chromium in the sediments was below EPA guidelines, so that exposure of the sediments as mudflats after dam breaching would not result in human health impacts.

ii. Fossil fuel electric power generation – Electricity generators that use fossil fuels continue to be the most common sources of US electricity generation. In all but 15 states, coal, natural gas, or petroleum liquids were the most-used fuel for electricity generation in 2017. Since 2007, the number of states where coal was the most prevalent source of electricity generation has fallen as natural gas, nuclear, and hydroelectricity have gained market share[11].

As detailed in the 2010 ANPRM, most environmental impacts of electric utilities relate to the type of fuel sources used to generate electric power. For example, burning coal as coal-fired power plants generates ash that contains contaminants like mercury, cadmium and arsenic. Without proper management, contaminants present in coal ash can pollute waterways, ground water, and drinking water. The need for federal action to help ensure protective coal ash disposal has been further highlighted by large spills such as those the TVA Kingston Plant and Duke Energy's Dan River Steam Station[12], which caused widespread environmental and economic damage to nearby waterways and properties.

Fossil fueled power plants burn large quantities of fuel and the associated waste is a relatively large volume of combustion products, with coal being the largest. Modern coal plants are fired by pulverized coal. Upon combustion. the coal reacts with oxygen to form carbon dioxide (CO_2). The combustion process is accompanied by the production of oxides of nitrogen (NO_x), sulphur dioxide (SO_2), fly ash, radionuclides and other by-products contained in coal. Substantial research has been completed on the environmental profile of this type of electric power generation. An extensive

[8]Milltown Resevoir Sediments accessed 10 Jun 2019 at https://cumulis.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.Cleanup&id=0800445#bkground and https://clarkfork.org/reflections-on-milltown-dam/

[9] FERC Press Release of 19 Jan 2005 "EPA to oversee hydroelectric facility dismantling as part of Superfund Remediation Project"

[10] Order Approving Surrender of License and Partial Removal of Project Works for Fort Halifax – accessed 10 Jun 2019 at https://www.ferc.gov/whats-new/comm-meet/012204/H-7.pdf

[11] U.S. Energy Information Administration, Electric Power Monthly accessed 10 Jun 2019 at https://www.eia.gov/todayinenergy/detail.php?id=37034

[12]EPA responses to coal ash accessed 10 Jun 2019 at https://www.epa.gov/tn/epa-response-kingston-tva-coal-ash-spill and https://www.epa.gov/dukeenergy-coalash

report on the "Wastes from the Combustion of Coal by Electric Utility Power Plants"[13] was first published by EPA back in 1988 and is still relevant today. The report details the variety of metals concentrations in ash sources from three coal regions, and in the ash waste type. At the time, fly ash, bottom ash, boiler slag and flue gas desulfurization (FGD) sludge accounted for approximately 90 percent of all wastes generated from the combustion of fossil fuels with 84M tons generated annually. According to the American Coal Ash Association's Coal Combustion Product Production & Use Survey Report[14], over 111M tons of coal ash was generated in 2017.

Additional types of wastes considered included boiler blowdown, coal pile runoff, cooling tower blowdown, demineralizer reagents and rinses, metal and boiler cleaning wastes, pyrites and sump effluents. The total amount of low-volume wastes generated from equipment maintenance and cleaning operations was smaller in volume than combustion wastes but were more likely to have higher concentrations of hazardous constituents. High levels were observed for several hazardous substances, including cadmium, chromium, lead, selenium, and arsenic. Detailed analyses of the quantities, characteristics, generation, exposure and risk variations on these waste and associated facilities can also be found in the 1997 EPA "Profile of the Fossil Fuel Electric Power Generation Industry"[15].

For fossil fuel power facilities, decommissioning will likely occur soon after the end of a plant's operating life. Decommissioning wastes will generally be those associated with demolition. Some may pose special residual hazards. Where onsite landfills and surface impoundments are used during operation, compliant and protective closure can be complex and challenging[16]. Ongoing EPA regulatory development in this area includes operation, monitoring, engineering structure and closure of CCR waste facility requirements.

iii. Nuclear electric power generation – This type of generation is less common and has a unique material and waste generation profile. The waste generated in the operation of nuclear power plants are relatively small volumes of radioactive materials. When the spent fuel is removed from the reactor, typically annually, it contains unconsumed uranium, fission products, plutonium and other heavy elements. It is possible to dissolve the spent fuel and chemically process (reprocess) it to extract the unused uranium and plutonium for fuel fabrication and recycling. Alternatively, the spent fuel elements can be disposed of directly as waste, without reprocessing. A typical nuclear power plant produces about 30 tons of high level radioactive spent fuel and reprocessing waste annually. This is in addition to low level wastes composed of protective clothing, cleaning and laboratory supplies and broken tools. According to a 2017 GAO report[17], the U.S. commercial power industry has generated nearly 80,000 metric tons. Spent fuel is currently stored in dry cask systems at 33 power plant sites[18].

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[13] Report to Congress. Wastes from the Combustion of Coal by Electric Utility Power Plants, EPA/530-SW-88-002 of February 1988

[14] American Coal Ash Association's Coal Combustion Product Production & Use Survey Report accessed 10 Jun 2019 at https://www.acaa-usa.org/publications/productionusereports.aspx

[15] EPA 310-R-97-007 of September 1997 "Profile of the Fossil Fuel Electric Power Generation Industry"

[16] US EPA Coal Plant Decommissioning, Remediation and Development Fact Sheet, 560-F-16-003

[17] COMMERCIAL NUCLEAR WASTE: Resuming Licensing of the Yucca Mountain Repository Would Require Rebuilding Capacity at DOE and NRC, Among Other Key Steps GAO-17-340: of May 26, 2017

[18] NEI Used Fuel Storage and Nuclear Waste report accessed 10 Jun 2019 at http://www.nei.org/resourcesandstats/nuclear_statistics/nuclearwasteamountsandonsitestorage/

Liquid waste treatment and management is a large issue at most nuclear facilities. Small quantities of aqueous wastes containing short-lived radionuclides may be discharged into the environment. Liquid wastes containing large salt concentrations can be evaporated with the radioactive material being retained in the concentrate or being chemically precipitated to produce a sludge with suitable properties for further treatment. Some liquid wastes can be absorbed on solid matrices, as a precursor to further treatment of the solid. Incineration is also sometimes used for volume reduction of active oils and combustible solvents.

When a nuclear power plant becomes uneconomic to operate or reaches the end of its license with the Nuclear Regulatory Commission (NRC), the plant either begins decommissioning and dismantling or is put into storage for decommissioning later. The NRC requires that decommissioning must be completed within 60 years of when the nuclear power plant shuts down. The NRC has produced an overview[19] of the decommissioning process and associated financial assurance. Most of the radioactive waste from decommissioning nuclear fuel cycle facilities is low-level solid waste. Small components of intermediate level and high-level or transuranic[20] waste are associated with reprocessing of spent fuel and the fabrication of mixed-oxide fuel.

iv. Solar electric power generation – Solar energy provides electrical power for distribution by utilities in sizes ranging from 10's of megawatts to 1,000 megawatts. Solar power plants can be stand-alone or hybrid plants in which solar and other power sources are combined. Solar panels are manufactured using hazardous materials, which can make them difficult to recycle. While operation of solar power facilities creates relatively small waste volumes, decommissioning can be more challenging.

The International Renewable Energy Agency 2016 report[21] on solar panel end of life management detailed that two-thirds of globally manufactured PV panels are crystalline silicon (c-Si). These are typically composed of more than 90% glass, polymer and aluminium, which are classified as non-hazardous waste. However, the same panels also include such hazardous materials as silver, tin and lead traces. Thin-film panels, by comparison, are over 98% non-hazardous glass, polymer and aluminium, combined with around 2% copper and zinc (potentially hazardous) and semiconductor or other hazardous materials. These include indium, gallium, selenium, cadmium, tellurium and lead. The report also projected US cumulative panel waste from industry and residential sources to range from 7.5 to 10M tons by 2050.

v. Wind electric power generation – Wind power converts the movement of air – wind - into electrical energy much in the same way as hydropower converts moving water into electricity. While operation of wind power facilities creates relatively small waste volumes, decommissioning may be more challenging. The high-tech blades used in wind turbines contain exotic compounds that are difficult to disassemble and recycle. These rotor blades use carbon fibers, glass and

[19]US Nuclear Regulatory Commission Decommissioning of Nuclear Facilities accessed 10 Jun 2019 at www.nrc.gov/about-nrc/regulatory/decommissioning.html

[20] Transuranic waste (also called TRU waste) is a regulatory classification of waste that applies only in the U.S. This type of waste contains more than 3700 Bq per gram of elements heavier than uranium (the elements with atomic number higher than 92).

[21]International Renewable Energy Agency End or Life Management: Solar Photovoltaic Panels accessed 10 Jun 2019 at https://www.irena.org/publications/2016/Jun/End-of-life-management-Solar-Photovoltaic-Panels

complex resins. While these solid wastes create reuse and disposal challenges, it is unlikely that extensive hazardous waste will be generated. According to the American Wind Energy Association[22], only a small number of projects have been decommissioned. Projects totaling only 43 megawatts (MW) of installed wind capacity were fully decommissioned in 2017. The decommissioning of wind turbines on federal lands is regulated by the Bureau of Land Management 2017 Solar and Wind Energy Rule[23]. Responsibility for decommissioning wind facilities on private lands is generally subject to local permitting conditions and contractual agreements between the energy company and the land owner.

vi. Geothermal electric power generation – Geothermal power plants are steam turbine systems with geothermal heat that produces steam. Power generation requires hazardous materials to abate air pollution and fuels for auxiliary equipment. Operational wastes include steam condensate (and associated treatment chemicals), cooling tower basin sludge, and by-product wastes from air pollution control equipment. The condensate may also contain high levels of boron, chloride, sulfates, nitrates and heavy metals. The cooling tower basin sludges commonly contain arsenic, mercury, nickel, and/or vanadium. Emissions of hydrogen sulfide are also an issue for geothermal power production.

Geothermal power plants can have potential impacts on water quality. Hot water pumped from underground reservoirs often contains high levels of sulfur, salt, and other minerals. Most geothermal facilities have closed-loop water systems, in which extracted water is pumped directly back into the geothermal reservoir after it has been used for heat or electricity production. Water is also used by geothermal plants for cooling and re-injection. Depending on the cooling technology used, geothermal plants can require between 1,700 and 4,000 gallons of water per megawatt-hour. However, most geothermal plants can use either geothermal fluid or freshwater for cooling; the use of geothermal fluids rather than freshwater clearly reduces the plants overall water impact[24].

For air emissions, the distinction between open- and closed-loop systems is important. In closed-loop systems, gases removed from the well are not exposed to the atmosphere and are injected back into the ground after giving up their heat, so air emissions are minimal. In contrast, open-loop systems emit hydrogen sulfide, carbon dioxide, ammonia, methane, and boron[25]. Some geothermal plants also produce small amounts of mercury emissions, which must be mitigated using mercury filter technology. Scrubbers can reduce air emissions, but they produce a watery sludge composed of the captured materials, including sulfur, vanadium, silica compounds, chlorides, arsenic, mercury, nickel, and other heavy metals. This toxic sludge often must be disposed of at hazardous waste sites. Some issues with transportation of geothermal wastes from

[22]American Wind Energy Association Decommissioning accessed 10 Jun 2019 at https://www.awea.org/policy-and-issues/project-development/state-and-local-permitting/decommissioning

[23]US Department of the Interior Bureau of Land Management Solar and Wind Energy Rule accessed 10 Jun 2019 at https://www.blm.gov/programs/energy-and-minerals/renewable-energy/laws/solar-and-wind-energy-rule

[24] Macknick, et al. 2011. A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies. Golden, CO: National Renewable Energy Laboratory. Accessed 10 Jun 2019 at https://www.nrel.gov/docs/fy11osti/50900.pdf

[25]Geothermal Energy Association report accessed 10 Jun 19 at http://www.geo-energy.org/pdf/reports/AGuidetoGeothermalEnergyandtheEnvironment10.6.10.pdf

remote and undeveloped areas have been reported[26]. A 1988 EPA study of wastes and operations of geothermal energy sector found no damage cases associated with this sector at the time[27] and such damage gases should remain uncommon to this day.

vii. Biomass electric power generation – Biomass and biofuels are a renewable energy source derived from living, or recently living organisms (i.e., not fossilized carbon), such as wood, waste, plants and algae. Biomass is generally considered solid fuel such as fuelwood, charcoal, agricultural crops and by-products, forest residues, industrial wood wastes and solid waste. Biofuels may also be derived from the conversion of biomass (organic material) into a combustible fuel. Biofuels may be gases such as methane or liquids such as ethanol or biodiesel.

Bioenergy use falls into two main categories: "traditional" and "modern". Traditional use refers to the combustion of biomass in such forms as wood, animal waste and traditional charcoal. Modern bioenergy technologies include liquid biofuels produced from bagasse[28] and other plants; bio-refineries; biogas produced through anaerobic digestion of residues; wood pellet heating systems; and other technologies.

Burning municipal solid waste (MSW, or garbage) in waste-to-energy plants could result in less waste buried in landfills. On the other hand, burning garbage produces air pollution and releases the chemicals and substances in the waste into the air. Some of these chemicals can be hazardous to people and the environment if they are not properly controlled. Strict CAA environmental rules apply to waste-to-energy plants, which require air pollution control devices such as scrubbers, fabric filters, and electrostatic precipitators to capture air pollutants. Scrubbers clean emissions from waste-to-energy facilities by spraying a liquid into the combustion gases to neutralize the acids present in the stream of emissions. Fabric filters and electrostatic precipitators also remove particles from the combustion gases. The particles—called fly ash—are then mixed with the ash that is removed from the bottom of the waste-to-energy furnace.

Ash from waste-to-energy plants can contain high concentrations of various metals that were present in the original waste. Textile dyes, printing inks, and ceramics, for example, may contain lead and cadmium. Separating waste before burning to exclude batteries and florescent light bulbs can reduce the amount of lead, cadmium, and mercury in this residual waste. RCRA requires that ash from waste-to-energy plants be tested to make sure that it is not hazardous. Some MSW landfills use ash that is considered safe as a cover layer for their landfills, and some MSW ash is reused to make concrete blocks and bricks.

Biogas forms from biological processes in sewage treatment plants, waste landfills, and livestock manure management systems. Biogas is a form of biofuel composed mainly of methane (a greenhouse gas) and CO2. Many facilities that produce biogas capture it and burn the methane to generate electricity[29], also regulated by the CAA (18).

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[26]Pasqualetti & Dellinger, Mar 1988, Journal of Energy and Development Hazardous Waste from Geothermal Energy: A Case Study, Journal of Energy and Development Vol 13, No 2, pgs 275-295

[27] EPA/530-SW-88-003D Management of Wastes from Geothermal Energy, Executive Summary of December 1987

[28] Bagasse is the dry pulpy residue left after the extraction of juice from sugar cane, used as biofuel for electricity generators.

[29] US Energy Information Administration, Biomass and the Environment accessed 10 Jun 2019 at https://www.eia.gov/energyexplained/index.php?page=biomass_environment

viii. Other (tidal) electric power generation – Tidal power is defined as projects that generate electricity from waves or directly from the flow of water in ocean currents, tides or inland waterways without use of a dam. This sector would include both wave and tidal energy. Wave energy uses converters to capture the energy contained in ocean waves to generate electricity. Converters include oscillating water columns that trap air pockets to drive a turbine; oscillating body converters that use wave motion; and overtopping converters that make use of height differences. Tidal energy is produced either by tidal-range technologies using a barrage (a dam or other barrier) to harvest power between high and low tide, tidal-current or tidal-stream technologies. The United States does not have any tidal barrage power plants[30]

Tidal turbines look like wind turbines. They can be placed on the sea floor where there is strong tidal flow. A demonstration tidal turbine project is under development in the East River of New York[31]. No waste issues were identified in association with this generation subsector at this time.

A tidal fence is a type of tidal power system that has vertical axis turbines mounted in a fence or row placed on the sea bed, like tidal turbines. Water passing through the turbines generates electricity. As of the end of 2017, no tidal fence projects were operating in the US.

B. **Transmission, Control & Distribution** – Electric power transmission is the bulk transfer of electrical energy between the point of generation and multiple substations near a populated area or load center. Transmission substations bring together energy generated by different points in the plant and use large transformers to increase voltage to reduce line losses during transmission. The transmission substation also has switches and circuits to control the electricity, and converters or inverters to convert the current to alternating current.

A power transmission network is referred to as a "grid." Multiple redundant lines between points on the grid are provided so that there are a variety of routes from any power plant to any load center. A distribution substation performs multiple functions, such as stepping down and stabilizing voltage going into distribution lines, splitting and routing distribution power in multiple directions, and disconnecting the transmission grid from the substation when necessary. A general overview[32] of electric power transmission was produced in 2014 by the Western Governor's Association.

As detailed by EPA[33], most significant environmental impacts of electricity relate to how it is generated. Electricity delivery can also affect the environment in several ways. High voltage power switches, inverters, converters, controller devices and other power electronics contain lead, brominated fire retardants, and cadmium in their printed circuit boards. These circuit boards must be managed properly to avoid posing risk to human health or the environment. Electrical substations and urban manhole facilities require periodic cleaning, which may yield hazardous waste. Additionally, insulating materials such as asbestos and polychlorinated biphenyls (PCBs) must also be managed properly.

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[30]US Energy Information Administration, Hydropower Explained accessed 10 Jun 2019 at https://www.eia.gov/energyexplained/index.php?page=hydropower_tidal

[31]Federal Regulatory Commission 19 July 2018 tidal power Order, accessed 10 Jun 2019 at https://www.ferc.gov/whats-new/comm-meet/2018/071918/H-3.pdf

[32] Western Governors' Association. 2014. An Introduction to Electric Power Transmission, accessed 10 Jun 2019 at https://openei.org/wiki/An_Introduction_to_Electric_Power_Transmission

[33]US EPA Electricity Delivery and its Environmental Impacts accessed 10 Jul 2019 at https://www.epa.gov/energy/electricity-delivery-and-its-environmental-impacts

Many high-voltage circuit breakers, switches, and other pieces of equipment used in the transmission and distribution system are insulated with sulfur hexafluoride (SF_6), which is a potent greenhouse gas. This gas can leak into the atmosphere from aging equipment or during maintenance and servicing. In collaboration with the industry Partners and stakeholders, EPA compiled a report[34] on SF_6 emission sources. The most common domestic use for SF_6 is as an electrical insulator in high voltage equipment that transmits and distributes electricity. Since the 1950's, the U.S. electric power industry has used SF_6 in circuit breakers, gas-insulated substations and other switchgear used in the transmission system to manage the high voltages carried between generating stations and customer load centers. Several factors affect SF_6 emissions from electric power systems, such as the type and age of the SF_6-containing equipment (e.g., old circuit breakers can contain up to 2,000 pounds of SF_6, while modern breakers usually contain less than 100 pounds) and the handling and maintenance procedures practiced by electric utilities.

PCBs also pose a challenge in transmission and distribution systems. PCBs used as dielectric insulators in transformers and capacitors are common throughout the industry[35]. Found in electrical transformers manufactured between 1929 and 1977, normal operation of this equipment means that the PCBs are entirely enclosed within the unit. When the equipment wears out, however, it can burn or break and leak PCBs. Although exposure no longer occurs through manufacture of PCB-containing products, it can still occur during the maintenance or repair of equipment that contains PCBs or because of accidents. A recent initiative to clean and refurbish urban electrical service manholes has increased activity and reduced associated release or exposure risks. Modern release risks from this legacy equipment is a somewhat common occurrence, though usually contained to a single substation or transformer. The concerns and cleanup requirements are fortunately well understood because of decades-old PCB regulations. Both Superfund incident response and EPA enforcement activities have also aided in further mitigating risks to this human health and environmental from this sector.

[34]US EPA Overview of SF_6 Emissions Sources and Reduction Options in Electric Power Systems of August 2018, accessed 10 Jun 2019 at https://www.epa.gov/sites/production/files/2018-08/documents/12183_sf6_partnership_overview_v20_release_508.pdf

[35]Identification, Management and Proper Disposal of PCB-Containing Electrical Equipment, accessed 10 Jun 2019 at https://www.epa.gov/sites/production/files/documents/pcbidmgmt.pdf