CHAPTER 5

5.0 ENERGY RESOURCE OPTIONS

5.1. Introduction

This chapter describes the various supply-side and demand-side options evaluated during the development of the IRP. It both describes the general characteristics of the options and the configurations considered in the various IRP strategies. In EV2020 (TVA 1995), TVA evaluated 100 supply-side and 60 demand-side resource options. The evaluation conducted for this IRP tiers from and incorporates these earlier evaluations.

5.2. Options Evaluation Criteria

TVA developed a long list of potential options to include in the various IRP strategies. This list was based on TVA staff expertise, public input during the IRP public scoping, and suggestions from the Stakeholder Review Group. To determine the options included in the various strategies, TVA evaluated potential options with the following criteria:

- The option must utilize a developed and proven technology, or one that has reasonable prospects of becoming commercially available before 2029.
- The option must be available to TVA either within the TVA region or importable through market purchases.
- The option must be reasonably economical and contribute to the reduction of emissions of air pollutants, including greenhouse gases, from the TVA power supply portfolio, in alignment with overall TVA objectives.

5.3. Options Excluded from Further Evaluation

Following is a list of options identified during the IRP scoping but, following screening, excluded from further evaluation (Table 5-1). Depending on future events, some of these resource options may be considered in more detail when TVA periodically updates the IRP.

Although not included in the IRP strategies, TVA is exploring the construction and operation of one or more small modular reactor nuclear plants and the deployment of electric vehicles. At least seven different corporations are developing these small modular reactors which have an electrical output of 10-335 MW (NRC 2010). These reactors would be manufactured in a factory and shipped by rail, truck or barge to the plant site. In most designs, the reactor containment vessel is underground and refueling cycles are longer than those of current reactors. Several of the developers intend to submit design certification applications to the Nuclear Regulatory Commission by 2013.

In 2009, TVA signed a letter of intent with Babcock & Wilcox to evaluate a site for an mPower reactor. The mPower reactor is a 125-MW modular reactor being designed by Babcock & Wilcox. TVA has identified its Clinch River Breeder Reactor site in Oak Ridge, Tennessee as a potential site for an mPower plant and in late 2010 began studies of its suitability, including environmental issues.

Table 5-1. Energy resource options identified during IRP scoping but excluded from further evaluation.

Energy Resource Option	Reason for Exclusion
Nuclear	
Small modular nuclear reactor	See text discussion of small modular reactors
Nuclear fuel reprocessing	This is a national issue and, as such, TVA will follow federal policies
Fast breeder reactor	In research phase and likely not ready during IRP planning period
Fusion reactor research	In research phase and likely not ready during IRP planning period
Gas turbine modular helium reactor	In research phase and likely not ready during IRP planning period
Complete Yellow Creek Nuclear Plant	Site is not available for a nuclear plant
Coal	
Plasma arc coal gasification	In research phase and likely not ready during IRP planning period
Replace old turbines in coal plants with new high efficiency turbines	Already considered this and found uneconomical
Utilization of lowest sulfur coals	This is already part of the compliance strategy for coal plants and is not a resource option
Stop use of coal from mountaintop removal mines	This is a fuel acquisition and environmental issue and not a resource option
Promote electric vehicles and their integration as energy storage systems	See text discussion of electric vehicles
Solar	
Space-based solar power	In research phase and likely not ready during IRP planning period
TVA self-build solar	The IRP considers solar resources; because of the tax incentives available to private developers, TVA will likely purchase solar power rather than build its own solar resources
Installation of PV panels on conveyors of fossil plants	The IRP considers solar resources; because of the tax incentives available to private developers, TVA will likely purchase solar power rather than build its own solar resources
Purchase PV panels in bulk, resell at cost, contract for installation	The IRP considers solar resources; because of the tax incentives available to private developers, TVA will likely purchase solar power rather than build its own solar resources
Solar cogeneration	While feasible with solar thermal plants, solar radiation in the TVA region is too low for cost-effective solar thermal plant development
Wind	
Installation of wind turbines on Shawnee Fossil Plant elevated dry ash stacks	It is unlikely that the ash stacks can provide a strong enough foundation for wind turbines

Table 5-1. Continued.

Energy Resource Option	Reason for Exclusion
Biomass	
Algal-based biofuel production at fossil plants utilizing captured CO_2 and waste heat	Waste heat applications were not considered because the opportunities for significant amounts of new generation from waste heat sources are limited
Cofiring biomass in natural gas facilities	Cofiring landfill gas is within the scope of potential power purchase agreements. To cofire solid biomass, the biomass must first be gasified; this technology is within the scope of potential renewable power purchases
Combustion of forest biomass	This is incorporated in the biomass options
Promote forest biomass resources for electric generation	While promotion of biomass is outside the scope of the IRP, the use of forest biomass is incorporated in the biomass options
High temperature combustion of municipal solid waste	TVA does not intend to construct or operate facilities using municipal solid waste as fuel but would consider purchasing power from such a facility
Renewable Energy (general)	
Expand Generation Partners program	The IRP includes the purchase of renewable energy
Support community owned wind and solar resources	The IRP includes the purchase of renewable energy
Direct payments for installation of renewable systems	The IRP includes the purchase of renewable energy
Loans for installation of renewable systems	The IRP includes the purchase of renewable energy
Natural Gas	
Replacement of coal plants with combined cycle plants	This option is considered in the IRP
Acquire and develop natural gas supplies	This is a fuel acquisition issue and not a resource option
Hydrogen / Fuel Cells	
Co-location of hydrogen production facilities at fossil or nuclear plants	The demand for hydrogen for use in fuel cells is not projected to be high enough to justify the additional required infrastructure
Combined Heat and Power (CHP)	
Promote CHP alternatives such as small gas turbines, microturbines, reciprocating engines, and fuel cells	Some of these options were considered in the IRP. They are also potential sources for power acquired through power purchase agreements
Waste heat recovery at natural gas generator stations	The potential for significant amounts of new generation from waste heat sources is limited. It is, however, a potential source of power acquired through power purchase agreements

Table 5-1. Continued.

Energy Resource Option	Reason for Exclusion
Heat pumps for commercial heat recovery	The potential for significant amounts of new generation from waste heat sources is limited. It is, however, a potential source of power acquired through power purchase agreements
Waste to Energy	
Promote waste to energy generation	Wood and other clean biomass wastes are a likely fuel source for the renewable generation included in the IRP. TVA does not intend to construct or operate facilities using municipal solid waste as fuel but would consider purchasing power from such a facility
Transmission	
Improve transmission line designs	This is an infrastructure issue and not an energy resource option, and therefore outside the scope of the IRP
Protect transmission grid against severe space weather events	This is an infrastructure issue and not an energy resource option, and therefore outside the scope of the IRP
Cooperate with other utilities in developing an 800-kV transmission system	The development of transmission needed to assure delivery of power is included in the IRP analyses.

Electric vehicles, like small modular reactors, are a focus area for TVA's research efforts. A major component of TVA's work with electric vehicles involves the construction and operation of prototype charging stations in partnership with ECOtotality North America and EPRI. TVA is also studying the integration of vehicle charging systems into the power grid and their potential effects of power demand. Electric vehicles are not expected to have a significant effect on the power system during the first few years of the IRP planning period.

5.4. Options Included in IRP Evaluation

Following is a description of the options included in the various IRP strategies. All of these options meet the criteria listed above. Environmental characteristics of these options, such as land requirements, air emission rates, water use, fuel consumption, and waste production are described in Chapter 7.

5.4.1. Fossil-Fueled Generation

Coal - Existing Facilities

TVA currently operates 59 coal-fired generating units at 11 generating plants with a total capacity of 14,500 MW (Table 3-3). While some strategies assume the continued operation of all of these plants, others assume placing different amounts of coal generating capacity (see Section 6.2) into long-term idled status (also known as mothball status in the power industry) for the foreseeable future. The goal of long-term idling is to preserve the asset so that it could be restarted in the future if power system conditions warrant. This preservation would require protection of plant equipment and materials from ambient conditions, particularly corrosion. This would likely require some modifications to the equipment. A variety of continuing equipment maintenance would also be required, such as periodic rotating of large equipment and lubrication. TVA would continue to maintain buildings and provide on-site security, and would likely employ a small on-site maintenance staff.

The determination of which coal units to idle and the timing of their idling is based on several factors including operating cost, forced outage rate, anticipated expenditures for environmental compliance, operation and maintenance cost, future ash handling costs, flexibility in handling different grades of coal, and the CO_2 emissions rate. Each unit was assigned scores for these factors. The units with the lowest rankings, and therefore candidates for layup, generally have high operating costs and high anticipated environmental compliance costs. Those units with the highest rankings generally have lower operating costs, fuel flexibility, low outage rates, and lower anticipated environmental compliance costs. In August 2010, TVA announced that the following nine coal units with a total capacity of about 1,000 MW would be idled:

- Two units at Widows Creek in 2011
- Shawnee Unit 10 in 2011, which will be evaluated for conversion to a dedicated biomass-fueled unit
- The remaining four older units at Widows Creek by 2015
- Units 1 and 2 at John Sevier by 2015.

TVA purchases the power generated by the 432-MW Red Hills coal-fired generating plant under a PPA extending through 2032. Unlike TVA's coal plants, the Red Hills plant burns low-Btu lignite mined from an adjacent surface mine in circulating fluidized bed boilers.

Coal - New Facilities

Because of the TVA objective of reducing greenhouse gas emissions and in anticipation of regulations restricting greenhouse gas emissions, options for new coal generating facilities were required to have carbon capture and storage (CCS) technology. Two types of coal plants, a supercritical pulverized coal (SCPC) plant with CCS and an integrated gasification combined cycle (IGCC) plant with CCS, were considered in the IRP evaluation. Both of these plant types are suitable for base load generation. Because of uncertainty over the viability of CCS, a CCS-equipped plant would not be built before 2025.

CCS is a process of reducing greenhouse gas emissions by capturing CO_2 produced in a power plant, compressing it, and transporting it to storage (see Section 4-4). The major components of a CCS system include CO_2 capture equipment, a pipeline to transport CO_2 from the plant to the sequestration site, and a compressor for injecting CO_2 into the storage medium. CCS systems add to the cost of a power plant and, because of the energy required to operate them, reduce the efficiency of the plant.

<u>Supercritical Pulverized Coal with CCS</u> - In a pulverized coal plant, finely ground coal is injected into the boiler (furnace) with sufficient air for combustion. The resulting heat boils water circulating in tubes within the boiler to produce steam which turns one or more turbines to generate electricity. An SCPC plant is a more recent version of the traditional pulverized coal plant that operates at higher temperatures and steam pressures between 3,200 and 4,400 pounds/square inch. SCPC plants operate at higher efficiencies (around 40 percent) and have lower emissions of air pollutants than "subcritical" pulverized coal plants. Major plant components include the coal receiving and storage area, boiler, steam turbine generator, air emissions control systems, stack, ash and gypsum handling and storage facilities, condenser cooling system and associated water supply, wastewater treatment system, office/maintenance buildings, transformer yard, and switchyard connected to the area electrical grid.

SCPC plants produce SO_2, NOx, mercury, CO_2, and ash as a result of burning coal. SO_2 is typically controlled in new SCPC plants by flue gas desulfurization systems (FGD or “scrubbers”). After fly ash is removed, the exhaust gases are mixed with finely ground limestone; the acidic SO_2 reacts with the basic calcium carbonate to form calcium sulfate and CO_2. If the calcium carbonate is in an aqueous solution, water is also produced by the reaction. The calcium carbonate (gypsum) is removed from the waste stream and sold for commercial use or deposited in a landfill. NOx is typically controlled in new SCPC plants by selective catalytic reduction (SCR) systems. In SCR systems, ammonia is mixed with the exhaust gases as they pass though a catalyst chamber. The resulting chemical reactions produce nitrogen and water. The combination of SCR and FGD systems also removes much of the mercury. SCPC plants require large volumes of water for operation of cooling towers. As previously stated in Chapter 4, new fossil and nuclear plants are assumed to have closed-cycle cooling systems which, relative to open-cycle cooling, decrease the volume of water used and heat discharged to the river but increases the amount of water consumed.

Two configurations of new SCPC plants are considered in the IRP evaluation:

- Single-unit 800-MW SCPC plant with CCS
- Two-unit 1600-MW SCPC plant with CCS.

Integrated Gasification Combined Cycle with CCS - An integrated gasification combined cycle (IGCC) plant converts coal into a gas composed primarily of hydrogen and carbon monoxide and then burns this gas in a combined cycle plant. The gasification process involves crushing the coal and then heating it in the presence of oxygen and steam. The resulting synthesis gas is cleaned by removing water vapor, CO_2, and sulfur compounds, which can be marketed. The synthesis gas, consisting primarily of hydrogen and carbon monoxide, can then be burned with very low SO_2 and NOx emissions. Heat is typically rejected to the atmosphere in a mechanical draft cooling tower. IGCC plants can burn a wide range of coals and be designed to use other carbon-based fuels, such as biomass. The gasification process can also be modified to produce liquid fuels and various chemicals.

Major plant components include the coal receiving and storage area, air separation unit, gasifier, synthesis gas treatment system (including CO_2 removal), combustion turbines, heat recovery steam generator, gasification ash and chemical byproduct handling systems, condenser cooling system and associated water supply, discharge water treatment system, office/maintenance building, transformer yard and switchyard connected to the area electrical grid, pipeline to CO_2 sequestration site, and CO_2 injection wells. The gasification components of an IGCC plant are complex and, at least at present, relatively expensive. The operating efficiency of an IGCC plant, however, is higher than a CT or conventional coal plant. Although there are few commercial-scale IGCC generating plants operating in the United States, several are currently proposed or under construction. The addition of CCS increases the plant construction and operating costs. TVA does not presently operate any IGCC plants, although it has considered them in the past (TVA 1997).

A new 490-MW IGCC plant with CCS designed to capture 90 percent of CO_2 emissions is considered in the IRP evaluation.

Natural Gas - Existing Facilities
TVA operates 11 natural gas-fueled generating facilities, 9 combustion turbine plants with a total capacity of 5,326 MW and 2 combined cycle plants with a total capacity of 1,327 MW (see Table 3-6). TVA is also constructing the 880-MW John Sevier combined cycle plant, scheduled for completion in 2012. Combustion turbine and combined cycle generating plants are described in more detail below. TVA also purchases power from three natural gas-fueled generating facilities (see Table 3-7).

Combustion Turbine - A simple cycle combustion turbine (CT) generator consists of an air compressor, combustor, and expansion turbine. Fuel is burned in the combustor, and the heated, high pressure combustion products drive the turbine, which drives the compressor and electric generator. The main fuel is natural gas, with fuel oil as the back-up fuel for most TVA CTs. CTs have low capital cost, short construction times, and rapid start-up, and are used for generating peaking power. Emissions are relatively low, as is their efficiency. Major plant components include the combustion turbines, generators, pipeline connection to the natural gas supply, fuel oil storage tanks, office/maintenance building, and transformer yard and switchyard connected to the area electric grid.

Combined Cycle - A combined cycle plant combines one or more CT generators with a heat recovery steam generator (HRSG). The hot exhaust gases from the CTs pass through the HRSG, where the steam powers a turbine-generator. Steam turbine exhaust is condensed and returned to the HRSG as feedwater and heat is rejected to the atmosphere in a mechanical draft cooling tower. The primary fuel is natural gas. Combined cycle plants are among the most efficient of conventional generators and are typically used for intermediate capacity additions. Additional peaking power can be generated by duct-firing, where natural gas is combusted in the CT exhaust gas stream to produce additional steam. Duct-firing, however, reduces the overall plant efficiency. The main combined cycle plant emissions are NOx, which is usually controlled by selective catalytic reduction, and CO_2. CO_2 emissions rates are the lowest of conventional fossil-fueled generators. Major plant components include the combustion turbines, heat recovery steam generator, air emissions control system, condenser cooling system and associated water supply, pipeline connection to the natural gas supply, office/maintenance building, and transformer yard and switchyard connected to the area electric grid.

Natural Gas - New Facilities
The following configurations of new natural gas generating facilities are considered in the IRP:

Combustion Turbine - The following CT plant configurations were considered:

- Upgrade of TVA's existing Gleason plant from 360 to 530 MW
- New 621 MW plant with three CTs
- New 828 MW plant with four CTs.

Combined Cycle - Three combined cycle plant configurations were considered:

- 513 MW plant consisting of 2 CTs and 1 HRSG
- 910 MW plant consisting of 3 CTs and 1 HRSG
- An existing 750 MW plant.

Petroleum
As noted above, TVA uses fuel oil as a backup fuel for many of its CT plants. TVA owns two diesel-fueled generating plants with a combined capacity of 13 MW. In these plants,

large diesel-fueled internal combustion engines drive electric generators. TVA also has several PPAs for a total of 120 MW of electricity generated by small (most < 1 MW) diesel units; these PPAs are expected to be phased out during the planning period. Diesel-fueled plants provide peaking generation. No additional diesel- or other petroleum-fueled plants are considered in the IRP evaluations, in part due to their high emissions of air pollutants.

5.4.2. Nuclear Generation

Nuclear - Existing Facilities

TVA operates three pressurized water units at two sites and three boiling water units at one site; these units have a total capacity of 6,900 MW (Table 3-5). The 1,150-MW pressurized water Watts Bar Unit 2 is scheduled to begin generating power in 2013. The total capacity includes anticipated capacity increases at Browns Ferry through the Extended Power Uprate project.

Nuclear generating plants use nuclear fission reactions to heat water to produce steam, which is then used to generate electricity. Nuclear plants in the United States are cooled and moderated by ordinary water; the two types of these “light water” reactors are pressurized water reactors and boiling water reactors. In the more common pressurized water reactors, coolant water is pumped under high pressure to the reactor core, and then the heated water transfers thermal energy to a steam generator. High pressure in the primary coolant loop prevents the water from boiling within the reactor. In boiling water reactors, coolant water pumped through the core boils and the steam then directly drives the turbine. In both designs, steam exiting the turbines is cooled in a condenser and recirculated. A separate water system cools the condenser, either with water circulated directly from a nearby reservoir or other water source, or circulated through a cooling tower. Nuclear plants provide base load generation. Major nuclear plant components include the reactor containment building housing the reactor vessel, the steam generators and reactor coolant pumps; turbine generators; spent fuel storage facility; condenser cooling system and associated water supply; office, control, and service buildings; wastewater treatment facility; transformer yard; and switchyard connected to the area electric grid. Nuclear plants produce very few air emissions, no direct CO_2 emissions, and discharge few water pollutants. They require large volumes of cooling water and, if operated in close-cycle cooling mode, consume large volumes of water (see Section 4.7).

Nuclear - New Facilities

In addition to the continued operation of the existing nuclear units, the completion of Watts Bar Unit 2, and the power uprates, new nuclear generating facilities considered in the IRP evaluation include the following:

- Completion of the 1,260-MW Bellefonte Nuclear Plant Units 1 and 2 pressurized water reactors
- Two new 1,117-MW Advanced Passive 1000 (AP1000) pressurized water reactors at Bellefonte (Bellefonte Units 3 and 4)
- A new 1,117-MW AP1000 reactor at an undetermined site.

TVA has recently taken several steps towards completing one or more nuclear units at Bellefonte. These, described in more detail in IRP Section 4.3.2, include submission of a Combined Construction and Operating License Application to the Nuclear Regulatory Commission for Units 3 and 4, reinstatement of the construction licenses for Units 1 and 2, and completion of detailed cost and engineering studies and a Final EIS for construction and operation of a single nuclear unit (TVA 2010c). On August 20, 2010, the TVA Board approved funding for additional engineering, design, and other activities at Unit 1 to maintain its feasibility for completion in 2018-2019. It is anticipated that the Board will be asked to approve the completion of Unit 1, depending on the outcome of the IRP in spring 2011.

5.4.3. Renewable Generation

TVA presently provides renewable energy from TVA facilities and acquired by PPAs. The renewable energy sources are hydroelectric, solar, wind and biomass-fueled facilities. As described below, renewable energy from these sources is considered in the IRP. Geothermal generation is not considered because it is not available in or near the TVA region.

Hydroelectric - Existing Facilities
TVA presently operates 110 conventional hydroelectric generating units at 29 dams with a combined capacity of 3,538 MW (Section 3.3). As also described in Section 3-3, TVA anticipates continuing its program of modernizing hydroelectric turbines, and the anticipated capacity increase of about 90 MW is included in most IRP strategies. TVA also has long-term power purchase agreements for 360 MW and 330 MW of hydroelectric capacity from SEPA and Alcoa, respectively (see Section 3-3). TVA hydroelectric plants are primarily operated to provide peaking power; during periods of abundant precipitation, they may also be operated to provide intermediate power. Their operation is described in more detail in the Reservoir Operations Study (TVA 2004). The continued operation of these facilities is evaluated in the IRP.

Hydroelectric generation uses the gravitational force of falling or flowing water to generate electricity. It is a form of renewable energy, as the water is not consumed while generating electricity. Operating costs are very low and no air pollutants are emitted. The reservoirs necessary for most conventional hydroelectric projects require large areas of land, but typically provide benefits in addition to electricity, such as flood control, water supply, and recreation. Typical components of conventional hydroelectric generating facilities include a dam, penstock (a pipe or sluice that transmits water from the dam to the turbine), gates to control the flow of water through the penstock, turbines, generators, and electrical transformers and switchyard connected to the area electrical grid. The turbines and generators are typically enclosed in a powerhouse, which may be located on the downstream face of the dam or of some distance downstream of the dam. The generating potential is proportional to the head, the difference in elevation between the water upstream of the dam and the turbines..

Hydroelectric - New Facilities
<u>Conventional Hydroelectric Facilities</u> - In addition to the continued operation of the existing hydroelectric plants, the IRP evaluates the following conventional hydropower options:

- Modernization of 38 generating units by 2029 with a resulting capacity increase of about 90 MW
- Addition of a 40-MW generator to an existing TVA hydroelectric plant
- Addition of a 5-MW generator to an existing TVA non-hydroelectric dam.

<u>Small and Low Power Hydroelectric Facilities</u> - As described in Section 4.17.3, the potential exists to develop small (between 2 and 60 MW) and low power (<2 MW) hydroelectric facilities on streams in the TVA region. These facilities include generators not requiring a dam and the addition of small turbines to existing dams. Hydroelectric generators not

requiring a dam, often called kinetic energy turbines or hydrokinetic generators, are currently under development by several companies in the U.S. and elsewhere and largely experimental at this time. The most common hydrokinetic generator under development uses turbines mounted on a pedestal on the river bottom or suspended from a barge or other structure (EPRI 2010). The turbines have an axis of rotation parallel to the current or an axis of rotation perpendicular to the current. The capacities of individual turbines under development are small, 25-40 KW, and developers anticipate deploying them in modular arrays of many turbines. Free Flow Power Corporation is in the early stages of developing hydrokinetic generation in the Mississippi River basin, including sites in the Mississippi River adjacent to the TVA region. The IRP evaluates up to 144 MW of small and low power hydro, likely acquired through PPAs.

Wind - Existing Facilities
TVA currently owns a 3-turbine, 2-MW windfarm and has PPAs with a 27-MW windfarm in the TVA region, a 300-MW windfarm in Illinois, and a 115-MW windfarm in Iowa (Section 3.4, Table 3-8). As noted in Section 3.4, TVA has pending PPAs with an additional 1080 MW of wind-generated power from six windfarms outside the TVA region. The continued operation of the existing facilities and completion of the pending PPAs is evaluated in the IRP.

Wind turbines generate electricity by capturing the wind's energy with blades that operate as airfoils. Land-based commercial-scale wind turbines are a mature technology and currently one of the most rapidly growing sources of electricity. Most commercial-scale wind turbines presently being deployed have generating capacities of 1.5-2.5 MW, towers 65-100 m tall, and blade diameters of 75-100 m. Turbines have been increasing in size for several years and the average capacity of turbines installed in 2008 was 1.7 MW (EPRI 2010). Because of transportation and other constraints, land-based turbines will likely be limited to 3-3.5 MW capacity and 100-110 m blade diameters in the future (EPRI 2010). Commercial wind turbines are usually deployed in arrays commonly called windfarms. The average size of windfarms has also increased and in 2007 was approximately 120 MW (EPRI 2010). The layout of turbines within a wind farm depends on the local terrain and land use conditions. On Appalachian ridges, such as TVA's Buffalo Mountain wind farm, turbines are typically in a single or multiple strings along ridgetops. On Midwestern farmland and Great Plains grasslands and shrublands, turbines are frequently arranged in clusters or parallel strings (Denholm et al. 2009) In addition to the wind turbines, the other major windfarm components are an electrical substation connected to the area electrical grid, access roads, and electrical lines (typically underground) connecting the turbines to the substation.

Wind - New Facilities
Because the potential and economics for wind energy development in the TVA region are not as great as in other parts of the U.S., TVA anticipates a large portion of wind energy it obtains in the future will be generated outside the TVA region. In addition, because TVA is not eligible for investment and production tax credits available to private developers, TVA assumes future additions of wind generating capacity will be through PPAs where these financial incentives can be used. The IRP evaluates the acquisition by PPAs of up to 2,380 MW of wind from outside the TVA region and 360 MW from within the TVA region. A small portion of this capacity may be from small wind turbines and purchased through the Generation Partners program (see Section 3-5). Small wind turbines typically have capacities of less than 100 KW. The most common designs use a 2- or 3-bladed horizontal

axis rotor with a diameter of 8-30 feet on a mono-pole tower 80-100 feet tall. Small wind turbines are typically owned by homeowners, farmers, and small businesses.

Solar - Existing Facilities

TVA owns 15 photovoltaic installations with a combined capacity of about 400 kW. TVA also purchases power from numerous photovoltaic installations through the Generation Partners program (see Section 3-5).

The two main types of solar electrical generation are photovoltaic (PV) and concentrating solar power (CSP). In PV cells, sunlight strikes semiconducting material, causing electrons to move between bands within the material and produce electricity. PV cells are usually packaged in flat modular panels and contain no moving parts. Panels may be mounted on buildings or on free-standing frames and are aligned to face south. The use of mounting systems which track the sun along one or two axes results in increased power generation but also increases installation costs. A more recent and still evolving approach is to integrate PV cells into building materials such as roofing and siding. CSP uses mirrors of various shapes to reflect sunlight onto a central receiver where fluid is heated to drive a turbine generator. The potential for CSP in the TVA region is relatively low because of atmospheric conditions (see Section 4.17.2).

Solar - New Facilities

As with wind generation, TVA is not eligible for investment and production tax credits to private developers. TVA therefore assumes that the great majority of future additions of solar generating capacity will be from PV systems and obtained through PPAs and purchases through the Generation Partners program. Most PV facilities in the TVA region have been in the 3-30 kW capacity range and installed by homeowners and small businesses. While installations of these small facilities will likely continue, there is a recent increase in installations of larger facilities of a few hundred kW to over 1 MW capacity. This trend will likely continue. The IRP evaluates the acquisition of up to 365 MW of solar capacity through PPAs.

Biomass - Existing Facilities

Biomass power plants can provide base load power and are one of few renewable power plants with generation that can be scheduled. TVA generates electricity by cofiring methane from a nearby sewage treatment plant at Allen Fossil Plant and by cofiring wood waste at Colbert Fossil Plant. This cofiring generated about 29,000 MWh in 2009. TVA presently purchases about 80 MW of biomass-fueled generation (Table 3-7). These purchases include 9.6 MW of landfill gas generation and 70 MW of wood waste generation. Biomass generating facilities can be classified by whether they use gaseous, liquid, or solid biomass fuels. Following is a description of generating facilities using gaseous and solid fuels, the most readily available biomass fuels in the TVA region (see Section 4.17.4).

<u>Gaseous Biomass-Fueled Facilities</u> - Landfill gas, a mixture of methane and CO_2, is produced by the decomposition of organic material in landfills. Air quality regulations require many landfills to prevent the release of this methane to the atmosphere, and thus have installed landfill gas collection systems. When used for generating electricity, the gas is cleaned to remove sulfur and other compounds and then used to fuel internal combustion engine-generators (modified diesel generator sets) with typical outputs of about 1 MW. System components include gas collection wells, pipes to transport the gas to a central point, the gas cleanup facility, a flare to burn excess gas, engine-generators, and a connection to the area electrical grid. The engine-generators are usually housed in a small

building. Typical system components for generating electricity from methane produced by composition of other types of organic material, particularly from sewage treatment plants and livestock manure management systems, are, except for the gas collection system, similar to those used for landfill gas systems.

Solid Biomass-Fueled Facilities - The most readily available types of solid biomass are forest residues, mill residues, and crop residues (Section 4.17.4). Municipal solid waste is a potential fuel in urban areas. While TVA does not intend to construct or operate facilities using it as fuel, TVA would consider purchasing power from such a facility. Dedicated biomass crops are also a potential fuel although their supply in the TVA region is presently very limited. The two principal types of solid-fueled biomass generation are cofiring at coal plants and dedicated biomass facilities. TVA periodically cofires wood waste at the Colbert plant and has experimentally cofired wood waste at the Allen and Kingston plants. Fuel availability and cost are major factors for both cofiring and dedicated biomass facilities. Because of transportation expenses, fuel sourcing areas are typically no farther than about 50 miles from the biomass plant (EPRI 2010). This constraint can limit the amount of cofiring or the size of a dedicated facility.

An alternative to delivering raw solid biomass to generating facilities is pretreatment at or near the harvest site. Potential pretreatment methods include sizing, drying, compacting, pelletizing and torrefaction. While these increase fuel costs, they can reduce transportation, storage, boiler operation, and ash disposal costs (EPRI 2009).

Cofiring currently is a relatively low cost approach to renewable generation and can be deployed relatively quickly. At cofiring facilities, biomass is fed into the boilers along with coal. The primary additions to an existing plant are the biomass receiving system, where trucks typically dump the fuel, a storage stockpile, and equipment for either blending the biomass with the coal as it is fed into the boilers or directly injecting biomass into the boilers (EPRI 2010). Depending on the type and quality of biomass fuel, a fuel screening and grinding system may also be used. In cyclone plants, such as Allen, the biomass can be blended with coal on the coal pile or on the conveyor feeding the coal bunkers. While cyclone plants can readily burn woody fuels, they are not suitable for switchgrass or other herbaceous fuels. In pulverized coal plants, such as Kingston and Colbert, woody biomass can be blended with coal on the conveyor feeding the coal bunkers or injected directly into the furnace. Switchgrass must be injected directly into the furnace, and direct injection of both woody biomass and switchgrass requires changes to the boiler. Biomass cofiring at both cyclone and pulverized coal plants reduces the plant efficiency by a small amount due to the lower energy content of biomass.

Dedicated Biomass Facilities - The most common types of dedicated facilities using solid biomass fuels are stoker boilers, cyclone boilers, and circulating fluidized bed boilers (EPRI 2010). Because of fuel availability constraints, the typical capacity of these facilities is about 50 MW. Typical components of these facilities include the fuel receiving and unloading system, fuel screening and grinding system, fuel stockpile area, fuel conveyor and feed bunker, boiler, turbine generator, cooling water supply and mechanical draft cooling tower, air heater, air emissions control systems, stack, transformers and electrical switchyard, connection to the area electrical grid, and office and service buildings. Emissions control systems typically consist of fabric filters or electrostatic precipitators to control particulates and selective catalytic reduction or selective non-catalytic reduction systems to control NOx. Biomass gasification also has potential for power generation, although most facilities built to date have been relatively small and used in combined heat and power applications (EPRI 2010).

An alternative to the construction of new dedicated biomass facilities is the conversion of existing coal-fired boilers to burn biomass only. The required plant changes depend on the type of fuel and its pretreatment, and can require construction of a new fuel handling system and boiler modifications. Dedicated biomass facilities are suitable for base load generation.

The IRP evaluates the following options for biomass-fueled generation at existing TVA coal plants:

- Biomass cofiring, for a total biomass-fueled capacity of up to 169 MW. Individual cyclone and pulverized coal boilers would have up to 20 MW of their capacity fueled by biomass.
- Conversion of existing boilers to dedicated biomass fueling, for a total capacity of up to 170 MW. Shawnee Fossil Plant Unit 10, the fluidized bed boiler, is being evaluated for conversion.

BIOMASS - NEW FACILITIES

The IRP evaluates acquiring up to 117 MW of biomass-fueled generating capacity through PPAs. Likely plant types include:

- Stoker boiler plant with a capacity of about 50 MW
- Dedicated biomass circulating fluidized bed plant with a capacity of about 50 MW.

After considering the costs, capacity factors, renewable resource potential, and other factors, TVA developed two renewable energy capacity expansion portfolios. Their development is described in more detail in IRP Appendix D. One portfolio (Table 5-2) associated with Strategies C, D and R is designed to achieve 2,500 MW of new renewable generating capacity by 2020. The other portfolio (Table 5-3) associated with Strategy E is designed to achieve 3,500 MW of new capacity by 2020. The 2,500 MW and 3,500 MW portfolios would generate about 8,600 and 12,000 GWh of energy in 2020, respectively. Strategies A and B contain no renewable additions beyond the renewable power purchase agreements described in Section 3.4. The out-of-region wind component of the two portfolios includes the pending power purchase agreements listed in Table 3-8.

5.4.4. Energy Storage

Energy storage facilities are used to store energy generated at times of low demand and then return it to the grid at times of high demand. The energy stored in the facility is typically generated by low-cost facilities such as nuclear and large coal units which operate most efficiently at a constant full load. Stored energy can also be generated by intermittent facilities operating at off-peak times such as windfarms. Using the stored energy during high peak demand periods can offset the need for more expensive, less efficient generation such as combustion turbines. Storage facilities can provide both peak and intermediate power.

Table 5-2. Renewable generation capacity (in cumulative MW) expansion portfolio associated with Strategies C, D, and R.

	Fiscal Year																	
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
HMOD						10	20	32	43	54	65	75	83	89	89	89	89	89
Landfill Gas	2	4	12	16	18	21	25	28	30	30	30	30	30	30	30	30	30	30
Addl Hydro		24	24	49	49	76	76	108	144	144	144	144	144	144	144	144	144	144
Cofiring		60	118	118	118	118	146	146	146	146	146	146	146	146	146	146	146	146
Wind																		
- Out-of-region	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380
- In region			50	100	150	200	250	300	360	360	360	360	360	360	360	360	360	360
Dedicated Biomass																		
- PPA		35	35	67	67	117	117	117	117	117	117	117	117	117	117	117	117	117
- Conversion			80	80	80	170	170	170	170	170	170	170	170	170	170	170	170	170
Solar	20	25	40	45	60	65	80	85	100	105	120	125	140	145	160	165	180	185
Total Capacity	1402	1528	1739	1854	1922	2157	2264	2365	2490	2506	2531	2547	2570	2581	2596	2601	2616	2621

Notes on table entries: HMOD - capacity gains from modernization of existing TVA hydroelectric turbines; Addl Hydro - small and low power hydro facilities; Cofiring - combustion of biomass in existing TVA coal-fired units; PPA - acquisition through power purchase agreement; Conversion - conversion of existing TVA coal-fired units to burn biomass only.

Table 5-3. Renewable generation capacity expansion portfolio associated with Strategy E.

	Fiscal Year																	
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
HMOD						10	20	32	43	54	65	75	83	89	89	89	89	89
Landfill Gas	2	4	12	16	18	21	25	28	30	30	30	30	30	30	30	30	30	30
Addl Hydro		24	24	49	49	76	76	108	144	144	144	144	144	144	144	144	144	144
Cofiring		60	118	118	118	141	169	169	169	169	169	169	169	169	169	169	169	169
Wind																		
- Out-of-region	1380	1480	1630	1780	1930	2080	2230	2380	2380	2380	2380	2380	2380	2380	2380	2380	2380	2380
- In region			50	100	150	200	250	300	360	360	360	360	360	360	360	360	360	360
Dedicated Biomass																		
- PPA		35	35	67	67	117	117	117	117	117	117	117	117	117	117	117	117	117
- Conversion			80	80	80	170	170	170	170	170	170	170	170	170	170	170	170	170
Solar	35	45	75	85	115	125	155	165	195	205	235	245	275	285	315	325	355	365
Total	1417	1648	2024	2294	2527	2940	3212	3468	3608	3629	3669	3690	3728	3744	3774	3784	3814	3824

Notes on table entries: HMOD - capacity gains from modernization of existing TVA hydroelectric turbines; Addl Hydro - small and low power hydro facilities; Cofiring - combustion of biomass in existing TVA coal-fired units; PPA - acquisition through power purchase agreement; Conversion - conversion of existing TVA coal-fired units to burn biomass only.

Energy Storage - Existing Facilities
TVA operates one large energy storage facility, the Raccoon Mountain Pumped Storage Plant. This plant has a capacity of 1,615 MW and can generate 1532 MW for 20 hours when fully charged. Its continued operation is considered in the IRP.

Pumped storage facilities operate by pumping water from a lower reservoir through pipes to a higher reservoir. The pumps can then be reversed to operate as turbine-generators when water flows from the higher reservoir to the lower reservoir. The amount of electricity generated is a function of the size of the storage reservoirs and the elevation difference (head) between the higher and lower reservoirs. Typical components of pumped storage facilities include the lower reservoir (which, in the case of Raccoon Mountain, may be an existing reservoir), upper reservoir, pipes connecting the reservoirs, reversible pump/turbine generators, electrical transformers and switchyard, connection to the area electrical grid, and office and service buildings. Depending on whether the pipes connecting the reservoirs are on the surface or underground, the pump/generators are located in an above-ground powerhouse or in an underground chamber. Large pumped storage facilities such as Raccoon Mountain have an efficiency of about 80 percent, meaning that for every 5 units of electricity used to pump water into the upper reservoir, 4 units are recovered during the generating cycle. Although they are net consumers of energy, they can be economically desirable because they consume energy during low-value periods and produce energy during high-value periods.

Energy Storage - New Facilities
The following new energy storage facilities are considered in the IRP:

- Pumped storage facility with a capacity of 850 MW
- Pumped storage facility with a capacity of 960 MW
- Compressed air energy storage facility with a capacity of 330 MW.

Compressed air energy storage (CAES) combines features of combustion turbines and pumped-hydro storage to provide peaking or intermediate power. It uses off-peak energy to compress air by a motor/generator compressor train, inject it into wells, and store it in an underground reservoir. During periods of high demand, the stored, pressurized air is released, heated, and passed through natural gas-fired high- and low-pressure turbines which drive the motor/generator. Turbine exhaust gas is used to heat the released air. A variation of this basic design, CAES with humidification, adds water vapor to the air entering the high-pressure turbine. A CAES facility would be used primarily for peaking power generation.

Surface facilities include the power block with the motor/generator compressor train, electrical transformers and switchyard, and office and service buildings, as well as the well field, compressed air pipelines, and a natural gas supply pipeline. TVA has investigated potential sites in northeast Mississippi that would use depleted natural gas fields in the Black Warrior geologic formation for the reservoir.

5.4.5. Energy Efficiency and Demand Response Options

TVA’s current EEDR portfolio is described in Section 3.5. New TVA EEDR programs considered in the IRP evaluation are listed below. Additional energy efficiency and demand reduction beyond that implemented by TVA may occur during the IRP planning period due to regulations, local and state statutes such as building code changes, state and federal incentive programs, and consumer behavior changes from education. These energy efficiency impacts are reflected in the need for power analysis in Chapter 2, and would be in addition to the results achieved from TVA programs. See Final IRP Appendix C for a description of the development of the EEDR portfolio associated with the Recommended Planning Direction strategy.

Residential Programs

- HVAC Maintenance - This program is focused on maintaining proper refrigerant charge and airflow across the coils in residential heat pumps and air-conditioning units. TVA will work with a third-party vender to offer a turnkey program.
- Weatherization Assistance - TVA has entered into an agreement with the Tennessee Department of Human Services under which TVA will provide curriculum development and training services for auditors and installers participating in the state Weatherization Assistance Program. In return, the Department is providing TVA with results of energy audits conducted before and after weatherization.

Commercial and Industrial Programs

- The present Commercial Efficiency Advice and Incentives Program would be split into the Industrial Efficiency Advice and Incentives Program, targeting industrial customers with less than 5 MW demand, and the Commercial Efficiency Advice and Incentives Program, targeting commercial businesses with billing demands greater than 50 kW. The incentives remain unchanged.
- Direct Installation (Small Commercial) - This program targets small commercial companies with less than 50 kW demand, such as small retail and office space tenants, with customized audits. Following the installation of identified energy efficiency improvements, customers could receive an incentive of up to $2,500.
- Retro/Re-Commissioning - This program is designed to optimize building performance by focusing on the interaction of building equipment and systems. Following screening to identify candidate buildings, the program would provide assistance for an audit of potential improvements to mechanical equipment, lighting, refrigeration, and related controls, training for building operators, and building monitoring. Incentive awards equivalent to $200/kW would be provided.
- White Tag - White Tags are energy trading certificates similar to Renewable Energy Certificates and equivalent to 1 MWh. They would be purchased from a third party for specific time periods relating to TVA's peak demand reduction needs. The third party would aggregate the tags and certify the demand and energy reductions.
- New Construction - This program is designed to provide incentives for businesses to invest in energy-efficient new commercial buildings and major renovation projects. The incentive options are based on HVAC and lighting systems and controls.
- Major Commercial - This program encourages reductions in electric energy intensity in large commercial facilities with a contract demand greater than 5 MW; about 65 large commercial customers are eligible. It offers customized technical assistance in taking a plant-wide, holistic approach to developing energy efficiency opportunities.
- Commercial Prescriptive - This program would offer incentives of $200/kW for reductions in electric energy intensity by commercial facilities with a demand less than 5 kW.
- Industrial Prescriptive - This program is similar to the Commercial Prescriptive program but aimed at industrial facilities with a demand less than 5 MW.

Education and Outreach

- National Energy Education Development Project - TVA, in partnership with state energy offices, would conduct energy management and education workshops for teachers, administrators, and facility staff at K-12 schools.
- District Projects - This program provides custom projects within TVA customer service districts.
- Valleywide Commercial Accounts - This program establishes single TVA points-of-contact for energy managers of corporations with multiple locations in the TVA region.
- Enhanced Security Deposit - This program provides a retail-based, credit insurance program as an alternative to collecting a two-month deposit for commercial and industrial customers with an electrical demand over 50 kW.
- Demand Response (SureGrid) - This program recruits customers to provide a demand response capacity under the SureGrid energy management system for up to 200 hours per year. Customers receive $35 per kW reduction.
- Direct Load Control - Under this program, two-way communication systems would be installed in homes of residential customers and TVA would remotely control water heaters and central air conditioners during peak load periods.
- Dynamic Voltage Regulation - This program is similar to the existing Conservation Voltage Regulation Program except that it uses the lower voltage on a dispatch basis instead of continuously.
- Biodiesel Generation - TVA would purchase electricity generated with biodiesel by end users in a manner similar to the existing Generation Partners program.
- Non-Renewable Clean Generation - TVA would purchase electricity generated by end users from clean but non-renewable sources. Eligible generation includes waste heat recovery, combined heat and power, and large industrial cogeneration. TVA would pay a 3-cent premium above the retail electric rate in a manner similar to the existing Generation Partners program.