Appendix B: Overview of the U.S. Electric System[1]

SECTION B.1: INTRODUCTION

Generating electricity from fossil fuels is the single largest source of anthropogenic carbon dioxide (CO2) emissions in the United States, representing 40 percent of CO2 emissions in 2008.[2] It is also the largest source of criteria air pollutants that affect air quality and human health. For these and other reasons there has been growing interest in understanding the impacts of state-level energy efficiency and renewable energy (EE/RE) policies on emissions from power generation. Much of this interest has come from state environmental regulators interested in including emission reductions from EE/RE policies in their plans for improving and maintaining air quality.

For these stakeholders and others working to analyze the effects of clean energy on air pollution emissions, there is a need to:

- Understand the electric system
- Understand how the system is likely to respond to the introduction of clean energy resources
- Conduct analysis that credibly and accurately represents this interaction and estimates reductions in air pollution

Appendix B is intended to address these needs[3]. It highlights the basic workings of the electric system and addresses important issues that arise in energy and emissions planning, most notably the "control strategy pathway" for state implementation plan (SIP)/Tribal Implementation Plan (TIP) quantification (see Appendix F). A key take-away from this Appendix is that the operation of regional power systems is complex and dynamic, so predicting how these systems will react to new resources – including energy efficiency and renewable energy – is likewise a complex undertaking.

SECTION B.2: ABOUT THE U.S. ELECTRIC SYSTEM

The most common way to generate electricity is to burn fossil fuels to convert water into steam, and to use the steam to spin a turbine that is connected to an electric generator. Generators can also be turned by water – as is the case with hydroelectric power plants – or by wind turbines. In all cases, the electricity generated at these facilities flows across the transmission and distribution system to where it is needed to meet customer demand in cities and rural areas.

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[1] This is taken from Appendix of the Draft Roadmap for Incorporating EE/RE Policies and Programs in State Implementation Plans/Tribal Implementation Plans. March 30, 2011.

[2] "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008," April 2010, Table ES-2.

[3] An additional resource for states interested in understanding the U.S. electric system is U.S. EPA's guidance, *Assessing the Multiple Benefits of Clean Energy: A Resource for States.* See: http://www.epa.gov/statelocalclimate/resources/benefits.html

The North American electric system is an interconnected network for generating, transmitting, and delivering electricity to consumers. Over the past 100 years, the system developed around a "central station" model that distributes power from large generating stations (often located near a fuel source) to customers located in load centers that are hundreds of miles away. The current electricity delivery system was designed and built in the 1950s to move large quantities of power from generators to consumers at low cost. Despite a recent trend towards more "distributed" power – in which small generation facilities are located near loads – most electric power in the U.S. continues to be generated at central-station facilities powered by coal, natural gas, nuclear, and hydropower.

The North American electric system is divided into four distinct grids in the continental United States and Canada: the Eastern, Western, Quebec, and Electric Reliability Council of Texas (ERCOT), as depicted in Figure B.2, *NERC Interconnections*. The generators, power lines, substations, and power distribution system are the responsibility of various utility companies working together under regional oversight to keep each grid operational. Each grid has only limited connections to the other three, but within them electricity is imported and exported continuously among numerous smaller power control areas (PCA).

PCAs are managed by system operators, or transmission organizations, whose main function is to maintain the reliability of the system in their areas (e.g., New England, New York, California, etc.). They do this by keeping the electricity supplied by the power plants in balance with that demanded by customers. This happens in real-time, every day of the year. In other words, energy is simultaneously being generated and consumed on each grid in the same quantity. There is very little ability to store electricity, and it is difficult for the grid to accommodate large, rapid changes in use and generation.

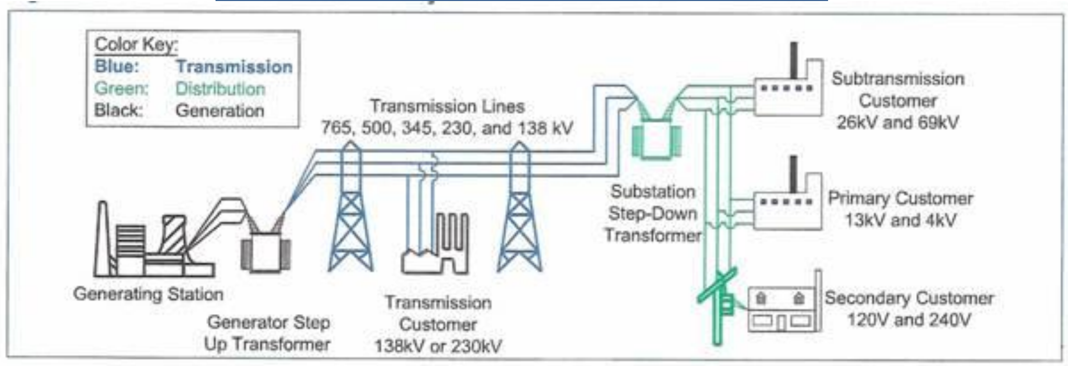
SECTION B.3: HOW THE ELECTRIC SYSTEM WORKS

Figure B.1 depicts the flow of power from the generating station, or power plant, to the transformer and transmission lines through a substation transformer (that reduces voltage) to the distribution lines. It then flows through the pole transformer to the consumer’s service box. Electricity *transmission* typically refers to power flow between the generating station and a substation, and electricity *distribution* most often refers to delivery from the substation to consumers. The flow of electricity occurs in accordance with the laws of physics—along “paths of least resistance,” in much the same way that water flows through a network of canals.

Over time in a given location, the consumer demand for power fluctuates significantly. For instance, residential electricity demand typically peaks in the morning and evening when residents are home and operating electricity-consuming products. In contrast, commercial electricity demand typically peaks during the middle of the day while industrial demand varies by individual firm and type of industry. System planners have to account for these variations as well as other factors such as weather and the availability of individual power plants, all while keeping the system in balance. Fortunately, the aggregate demand of the many jurisdictions across a single grid behaves in a relatively predictable manner.

To meet consumer demand, the grid operators rely on a fleet of power plants with different operational characteristics, fuels, and cost structures. Base load plants such as nuclear and most

Figure B.1: System Flow of Electricity



coal plants operate 24 hours a day and do not readily cycle up and down. They are meant to start up and keep running until maintenance is needed. Base load units are also characterized by relatively high capital costs and a ramp-up process that is slow, expensive, and results in wear on the generating units. As power demand increases over the course of a day, intermediate and peaking plants come on line. These plants have the physical capability to quickly ramp up power production to meet increasing demand and rapidly cycle down once that demand dissipates. These plants are often engines or turbines that are fueled by oil or natural gas (see Figure B.3).

The Marginal Unit

- The highest-cost unit dispatched at any point in time is said to be "on the margin" and is known as the "marginal unit." At peak times, for example, high-cost combustion turbines and gas/oil peaking units are frequently on the margin. During off-peak times, plants with lower operating costs (e.g., combined cycle gas turbines and coal-fired steam units) can be on the margin. In some regions the cost used to determine merit order for dispatch is the variable cost of running each plant (mainly fuel cost), but in other regions the criterion for dispatch is a bid price submitted by the owners of the generators

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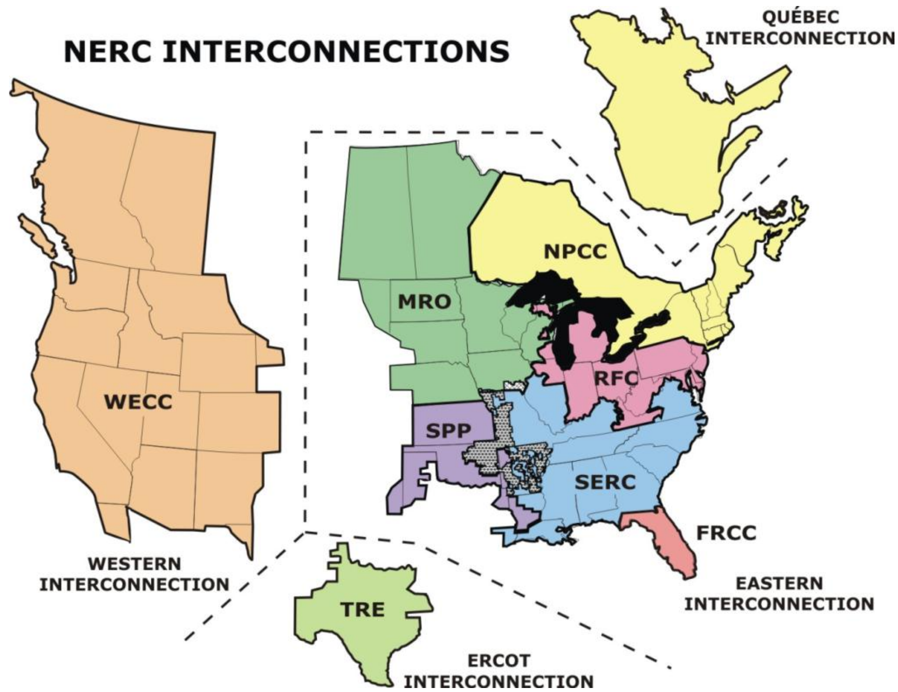
The decision of which power plants to dispatch and in what order is based in principle on economics, with the lowest-cost resources dispatched first and the highest cost resources last. The last resources to be called upon are referred to as the marginal units, which are typically the most expensive units to run. In some cases in certain parts of the country, these plants can also be among the dirtiest and least efficient of the power plant fleet.

Renewable energy and energy efficiency can affect the dispatch in different ways, though both cause marginal units to run less frequently and result in fewer air emissions. In the case of efficiency, energy consumption is lowered at the point of consumption resulting in a reduction in demand on the electric system and a corresponding reduction in emissions from the power plant fleet.

Figure B.2: NERC Interconnections



In contrast, renewable energy sources reduce the output from the marginal unit by producing electricity for the power. Thus, a wind farm producing electricity displaces the need for electricity that would have otherwise been produced by that marginal unit. Since wind power results in zero emissions, overall emissions from the power plant fleet are reduced (absent a cap on emissions that determines overall pollution levels).

This theory of "economic dispatch" predicts that any new resource shifts upward all resources above it in the dispatch order, reducing demand on the marginal unit (the most expensive unit needed to meet demand). Actual plant dispatch, however, is frequently more complicated than the representation in Figure B.3 for three main reasons:

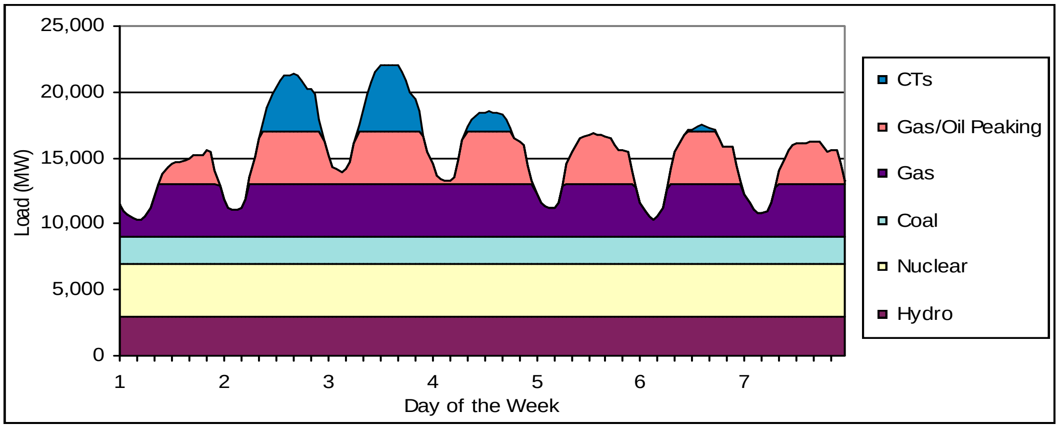
- Transmission constraints may require system operators to dispatch certain units that are more expensive than other available units.

- It is time consuming to start and stop many types of large generating units. Limitations on unit "ramp-up rates" also force system operators to keep some units running during periods when they are not needed (in order to have the units available when they are needed). These are referred to as load following, or intermediate units, and are often running at a lower and less efficient rate while not producing any power for input into the grid.

- System operators do not treat generating units as single entities in the dispatch process. Instead, plant owners in competitive markets typically bid the power from an individual generating unit into a smaller number of "blocks" that are instead bid into the grid.

Because actual unit dispatch often looks very different from the ideal shown in Figure B.3., environmental regulators and others should be aware of how these electric-system realities are represented in control-measure estimates of emissions reductions.

Figure B.3: Unit Dispatch in a Power System



SECTION B.4: THE LOCATION OF EMISSIONS REDUCTIONS RELATIVE TO THE SITING OF CLEAN ENERGY RESOURCES

The goal of clean energy policies in the SIP planning context is typically to reduce emissions within the state, tribal area or region where the policies are implemented. To achieve this goal, all (or a portion of) the emissions reductions from EE/RE must occur in a location that affects air quality in the implementing jurisdiction. The environmental regulator can take steps to ensure that the analysis supporting such a policy accounts for the interconnected and dynamic nature of the power system, and that it examines the possibility that the benefits of clean energy policies may not be completely realized within the jurisdiction of interest.

This can be illustrated by the example of a state with a renewable portfolio standard requiring utilities to buy a fixed percentage of their electricity from renewable energy facilities. If a local utility signs an energy-purchase contract with the nearest renewable facility, the state may find it difficult to correlate wind power produced by that wind farm to a corresponding reduction in electric output and emissions from specific fossil-fuel generators. The implementing state needs to ensure that the emission reductions occur at an upwind or nearby facility that affects the implementing state's air quality.

For this reason, it is critically important to understand and accurately predict how the regional power grid is likely to behave when assessing the emissions benefits from clean energy resources.