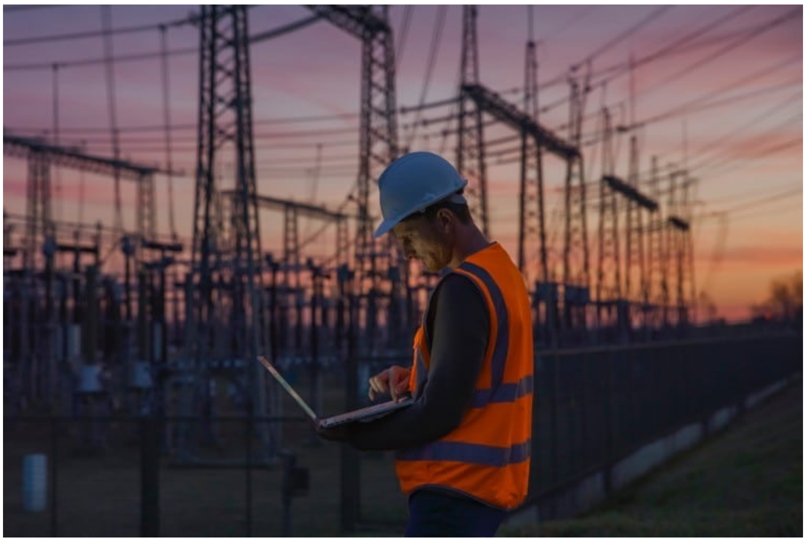
Back to Energy's Future? — Part 2

As indicated in the first article of this series, there are two very important electricity-generating system performance measures that must be considered when making decisions about what energy resources should be pursued to obtain abundant, affordable, and reliable electricity: energy conversion system efficiency and system capacity factor. The former performance measure will be addressed in this article, while the latter will be addressed in the next article in this series.



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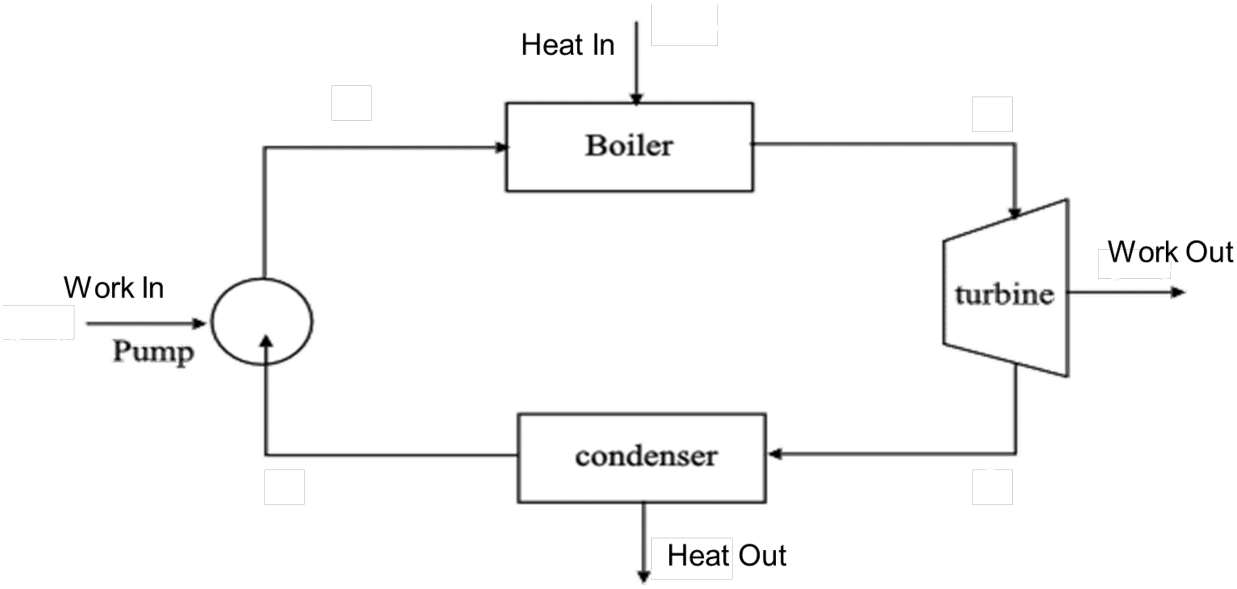
Furthermore, the discussion of these performance measures will be limited to coal, natural gas, uranium, solar, and wind resources, as these resources are the focus of current energy debates. Water as an energy resource will not be addressed because there is no possibility of any significant future expansion of hydroelectric facilities in the United States.

Energy Conversion Efficiency

Most energy forms cannot be converted completely into work, even under ideal conditions. When one energy form is converted to another energy form, some energy will always be dissipated to the environment as waste heat. That portion of energy that can theoretically be converted into work is called *available energy*, whereas the portion that is actually converted into work is called *useful energy*.

The ratio of useful energy to available energy is the energy conversion efficiency, which will always be less than 100 percent. The efficiency of an electricity-generating system can be found by multiplying the efficiencies of the system's energy-conversion devices. (Efficiencies for most energy-conversion devices can be found on the internet.)

Coal-fired and nuclear power plants generate electricity using a conventional steam cycle, depicted in the graphic below. Both of these fuels provide the heat that creates high pressure, high temperature steam in the boiler. The steam drives a turbine connected to an electrical generator. The electricity-generating efficiency of these power plants is typically about 33 percent, but may approach 40 percent.



The efficiency of a simple gas-turbine power plant is typically about 35 percent, but may approach 40 percent.

A photovoltaic facility generates electricity by converting photon energy (sunlight) into direct current, which is then converted to alternating current by a DC to AC inverter. Solar-cell efficiency is a measure of how much of the electromagnetic radiation (photons) incident on the cell is converted to electrical current. Photons above a certain energy level will create an electrical current in a photovoltaic panel, while photons of less energy will deposit thermal energy in the panel that is ultimately lost to the environment. In fact, the physics boundary for silicon PV cells, the Shockley-Queisser Limit, is a maximum conversion of 33 percent of photons into electrons.

Most photovoltaic panels are between 15 and 20 percent efficient. High-quality panels can exceed 22-percent efficiency in some cases, but the majority of panels do not achieve efficiencies above 20 percent. A typical solar inverter has an efficiency of greater than 94 percent. Therefore, a photovoltaic facility has a maximum efficiency of about 20 percent.

A wind turbine generates electricity by converting wind energy into mechanical energy of a rotating shaft. A gearbox increases the shaft speed to drive a permanent magnet generator. The Betz Limit specifies that no wind turbine can capture more than about 59 percent of the kinetic energy of the wind (when the exit wind velocity is 30-40 percent of the incident wind velocity).

Typically, wind turbines have a maximum efficiency of around 40 percent. If a maximum gearbox efficiency of 95 percent is assumed, together with a maximum permanent magnet generator efficiency of 95 percent, then the system would have a maximum efficiency of about 36 percent.

It must be pointed out that these efficiencies would be expected for electricity-generating systems at the beginning of life. Equipment performance generally degrades over time, so system efficiencies would also be expected to decline somewhat over time.

Battery Energy Storage System Efficiency

Battery energy storage systems have been proposed to compensate for the intermittency of solar- and wind-generated electricity in a 100-percent renewables scenario. The efficiency of storing and recovering wind and solar energy is 60 to 70 percent for lead-acid storage batteries and 87 to 94 percent for lithium-ion batteries.

Assuming an average efficiency of 90 percent for lithium-ion batteries, the efficiencies of solar and wind systems that generate and store electricity are then about 18 percent and 32 percent, respectively.

Other articles in this series:

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