Life cycle assessment comparisons of electricity from biomass, coal, and natural gas

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The generation of electricity, and the consumption of energy in general, result in consequences to the environment. Using renewable resources and incorporating advanced technologies such as integrated gasification combined cycle (IGCC) may result in less environmental damage, but to what degree, and with what trade-offs? Life cycle assessment (LCA) studies have been conducted by the National Renewable Energy Laboratory on various power generating options in order to better understand the environmental benefits and drawbacks of each technology. The systems that were studied are:

1) a biomass-fired integrated gasification combined cycle (IGCC) system using a biomass energy crop,
2) a direct-fired biomass power plant using biomass residue,
3) a pulverized coal (PC) boiler representing an average U.S. coal-fired power plant,
4) a system cofiring biomass residue with coal, and
5) a natural gas combined cycle power plant.

Each assessment was conducted in a cradle-to-grave manner to cover all processes necessary for the operation of the power plant, including raw material extraction, feed preparation, transportation, waste disposal, and recycling. A summary of the energy balance, global warming potential (GWP), air emissions, and resource consumption for each system is given.

Material and energy balances were used to quantify the emissions, energy use, and resource consumption of each process required for the power plant to operate. These include feedstock procurement (mining coal, extracting natural gas, growing dedicated biomass, collecting residue biomass), transportation, manufacture of equipment and intermediate materials (e.g., fertilizers, limestone), construction of the power plant, decommissioning, and any necessary waste disposal.

Each study was conducted independently and can therefore stand alone, giving a complete picture of each power generation technology. However, the resulting emissions, resource consumption, and energy requirements of each system can ultimately be compared, revealing the environmental benefits and drawbacks of the renewable and fossil-based systems. Completing several life cycle assessment studies has allowed us to determine where biomass power systems reduce the environmental burden associated with power generation. The key comparative results can be summarized as follows:

- The GWP of generating electricity using a dedicated energy crop in an IGCC system is 4.7% of that of an average U.S. coal power system.
- Cofiring residue biomass at 15% by heat input reduces the greenhouse gas emissions and net energy consumption of the average coal system by 18% and 12%, respectively.
- The life cycle energy balances of the coal and natural gas systems are significantly lower than those of the biomass systems because of the consumption of non-renewable resources.
- Not counting the coal and natural gas consumed at the power plants, the net energy balance of these systems is still lower than that of the biomass systems because of energy used in processes related to flue gas clean-up, transportation, and natural gas extraction and coal mining.
- The biomass systems produce very low levels of particulates, NO_x, and SO_2 compared to the fossil systems.
- System methane emissions are negative when residue biomass is used because of avoided decomposition emissions.
- The biomass systems consume very small quantities of natural resources compared to the fossil systems.
- Other than natural gas, the natural gas IGCC consumes almost no resources.

A sensitivity analysis was conducted on each system to determine which parameters had the most influence on the results and to pinpoint opportunities for reducing the environmental burden of the system. In general, parameters associated with increasing the system efficiency and reducing the fossil fuel usage had the largest effects on the results. Additionally, for the biomass systems, variables associated with growing a dedicated feedstock and factors affecting how much CO_2 and CH_4 are avoided by using biomass residue significantly affected the GWP of the system. Overall, however, the sensitivity analyses demonstrated that the conclusions that could be drawn from these studies remain relatively constant as different parameters are varied.

The results demonstrate quite clearly that biomass power provides significant environmental benefits over conventional fossil-based power systems. In particular, biomass systems can significantly reduce the amount of greenhouse gases that are produced, per kWh of electricity generated. Additionally, because the biomass systems use renewable energy instead of non-renewable fossil fuels, they consume very small quantities of natural resources and have a positive net energy balance. Cofiring biomass with coal offers us an opportunity to reduce the environmental burdens associated with the coal-fired power systems that currently generate over half of the electricity in the United States. Finally, by reducing NOx, SOx, and particulates, biomass power can improve local air quality.