# The net energy and global warming potential of coal-fired electricity with $CO_2$ sequestration compared to biomass power - a life cycle approach

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## Introduction

It is technically feasible to capture $CO_2$ from the flue gas of a coal-fired power plant and various researchers are working to understand the fate of sequestered $CO_2$ and its long term environmental effects. Sequestering $CO_2$ significantly reduces the emissions from the power plant itself, but this is not the total picture. $CO_2$ capture and sequestration consumes additional energy, thus lowering the plant's fuel-to-electricity efficiency. To compensate for this, more fossil fuel must be procured and consumed to make up for lost capacity. Taking this into consideration, the National Renewable Energy Laboratory (NREL) examined the GWP and energy balance of coal-fired power generation which incorporates $CO_2$ capture and sequestration assuming a constant power generation capacity is maintained. To understand the overall environmental implications, a life cycle approach, which takes into account the upstream process steps, was applied. It is important to include the upstream emissions because these remain constant after $CO_2$ sequestration. The reference system consisted of coal mining, transportation, and power plant operation. In order to maintain power generation capacity, additional capacity must come from another source. Two sources were examined: extra capacity from a natural gas combined-cycle (NGCC) system or extra capacity from the grid. To examine the potential environmental benefit of biomass power, the net energy and GWP of these coal systems were compared to the results of previously performed life cycle assessments on two biomass power generation technologies: a biomass-fired integrated gasification combined cycle (IGCC) system using a biomass energy crop and a direct-fired biomass power plant using biomass residue.

## Approach

First, a reference system needed to be established for the coal-fired power plant. The reference plant is a 600 MW pulverized coal-fired power plant and the system consists of coal mining, transportation, and power plant operation prior to adding $CO_2$ capture and sequestration. After adding $CO_2$ capture via a monoethanolamine system, the $CO_2$ was compressed, transported via pipeline, and sequestered in underground storage such as a gas field, oil field, or aquifer. The energy requirements for capturing and compressing the $CO_2$ were subtracted from the gross output of the power plant. To examine the effect of distance, the $CO_2$ transport distance was varied from 300 km to 1,800 km then the $CO_2$ was discharged to an underground depth of about 800 m. To recover the pipeline pressure drop, compressor stations were assumed to be at 300 km intervals. Emissions and energy use associated with re-compression along with building, drilling, and laying the pipeline were included in the analysis.

$CO_2$ capture and sequestration consumes additional energy, therefore, in order to maintain power generation capacity, additional capacity must come from another source. Two scenarios were examined to account for the capacity loss: adding extra capacity from a natural gas combined-cycle system and adding extra capacity from the grid. The NGCC system was chosen because this type of power generation is currently being constructed and future power plants are anticipated to be NGCC. For the grid option, the mid-continental U.S. generation mix was used.

**Study Showed**

This analysis showed that capturing $CO_2$ from flue gas of a coal-fired power plant and sequestering it in underground storage such as a gas field, oil field, or aquifer can reduce the GWP of electricity production but the penalty is a substantial increase in fossil energy consumption. First, capturing and compressing flue gas $CO_2$ results in a large decrease in the power plant efficiency. The power plant efficiency prior to $CO_2$ capture and sequestration is 41% (LHV basis) and the new power plant efficiency with $CO_2$ capture and compression is reduced by 9.8 percentage points to 31.2%. Secondly, maintaining a designated capacity means that additional electricity production must come from another source, most likely a fossil-fueled power station. Table 1 summarizes the GWP and energy consumption for the fossil and biomass power systems studied in this analysis. Although there is a substantial decrease in the GWP, sequestering 90% of the $CO_2$ from the flue gas of a coal-fired power plant does not equal a 90% reduction in the GWP per kWh of electricity produced. Additionally, the amount of fossil energy consumed to maintain power generating capacity can increase by as much as 25%. However, substituting electricity generated by fossil fuels with biomass electricity will substantially reduce the GWP along with significantly decreasing the fossil energy consumption per kWh of electricity generated.

**Table 1: Comparison of GWP and Energy Balance for Fossil and Biomass Power Systems**

| Case | Fossil energy consumed to produce 600 $MW_e$ ($MW_{th}$) | Net GWP (million tonnes $CO_2$-equivalent/yr) | Change from reference system | |
|---|---|---|---|---|
| | | | Fossil energy consumption | GWP |
| Coal-fired reference system | 2,090 | 4.44 | N/A | N/A |
| Coal w/$CO_2$ seq. plus NGCC | 2,435 | 1.30 | 16.5% | -70.7% |
| Coal w/$CO_2$ seq. plus grid | 2,607 | 1.80 | 24.7% | -59.5% |
| Biomass IGCC | 38 | 0.25 | -98.2% | -94.4% |
| Biomass direct-fired | 21 | -2.15 | -99.0% | -148.4% |

Note: The GWP, which is a combination of the following GHG emissions: $CO_2$, $CH_4$, and $N_2O$, were calculated at 100% capacity for a 600 MW system.

**Issues**

While transportation of compressed $CO_2$ has been demonstrated, important issues involving safety and reliability remain prior to large scale deployment. Also, there is much debate about the fate of the sequestered $CO_2$ and its long term environmental effects. Additionally, capturing, compressing, and disposing of the flue gas $CO_2$ is expensive, thus power generation via biomass may be more economical and this technology would avoid the issues involved in sequestering $CO_2$. Work is being done at NREL to compare the economics in conjunction with the GWP and energy balance of biomass power to electricity production via coal plus $CO_2$ sequestration and even via natural gas with $CO_2$ sequestration. This will tell us the cost of avoiding green house gas emissions and reducing fossil energy consumption per kWh of electricity produced by using the more expensive biomass technology over conventional fossil systems.