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Comparative life cycle assessment of biomass co-firing plants with carbon capture and storage

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HIGHLIGHTS

- The impact of co-firing biomass on coal-fired power plants with CCS is assessed.
- BioCCS is an effective option to obtain net negative CO_2 emissions.
- BioCCS increases the impact in other environmental categories.
- BioCCS with pre-combustion CO_2 capture is the most sustainable option.
- CO_2 reduction due to BioCCS outweighs impact increase in other categories.

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ABSTRACT

Combining co-firing biomass and carbon capture and storage (CCS) in power plants offers attractive potential for net removal of carbon dioxide (CO_2) from the atmosphere. In this study, the impact of co-firing biomass (wood pellets and straw pellets) on the emission profile of power plants with carbon capture and storage has been assessed for two types of coal-fired power plants: a supercritical pulverised coal power plant (SCPC) and an integrated gasification combined cycle plant (IGCC). Besides, comparative life cycle assessments have been performed to examine the environmental impacts of the combination of co-firing biomass and CCS. Detailed calculations on mass balances of the inputs and outputs of the power plants illustrate the effect of the different content of pollutants in biomass on the capture unit. Life cycle assessment results reveal that 30% co-firing biomass and applying CCS net negative CO_2 emissions in the order of 67–85 g/kWh are obtained. The impact in all other environmental categories is increased by 20–200%. However, aggregation into endpoint levels shows that the decrease in CO_2 emissions more than offsets the increase in the other categories. Sensitivity analyses illustrate that results are most sensitive to parameters that affect the amount of fuel required, such as the efficiency of the power plant and assumptions regarding the supply chains of coal and biomass. Especially, assumptions regarding land use allocation and carbon debt of biomass significantly influence the environmental performance of BioCCS.

1. Introduction

Carbon Capture and Storage (CCS) is increasingly gaining attention as a strategy for the abatement of greenhouse gas (GHG) emissions. The 2 °C scenario in the Energy Technology Perspective Report [1] predicts that CCS will play a vital role in mitigating the anthropogenic CO_2 emissions with a share of 20% of the total global emissions reduction by 2050. It is predicted that given the technical limitations, around 30–60% of the CO_2 emissions from electricity generation and 30–40% of those from industry (in total accounting for 20–40% of global fossil fuel CO_2 emissions) are expected to be mitigated by CCS in the time period between 2010 and 2050 [2]. To reach the 2 °C scenario, 63% of coal-fired electricity generation (630 GW) needs to be equipped with CCS

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by 2050 [1]. The importance of CCS in the future of the energy system and the potential for CCS deployment have been widely highlighted in literature (e.g. [3–8]).

Although CCS is often associated with the use of fossil fuels, it can also be combined with the use of biomass, often referred to as BioCCS or BECCS [9,2]. The share of biomass use in the energy system can exceed 27% in 2050 [7]. In the shorter term, Panoutsou et al. [10] and Hoefnagels et al. [11] estimated the potential share of biomass in Europe's energy system in 2020 to increase to 10.6% and 14.0%, respectively. Considering this expected increasing share of biomass in the future energy system, BioCCS offers an attractive potential for a net removal of carbon dioxide from the atmosphere, as is already highlighted by many studies [9,12–16]. Moreover, BioCCS development could help to avoid the risk of reinforced fossil fuel lock-in which is associated with the implementation of CCS in conventional fossil fuel power plants [17].

The concept of BioCCS is not restricted to production of electricity or heat but can also be integrated to, for instance, biofuel production units such as biogas plants [18], hydrogen production plants and industrial processes. Different biomass based conversion options with CCS are presented in Fig. 1.

IEAGHG [19] identified and evaluated the technical potential of six of the most promising BioCCS options namely; Pulverized Coal power plant with biomass co-firing (PC-CCS co-firing); Circulating fluidized bed combustion power plant, with a 100% biomass share (CFB-CCS dedicated); Integrated gasification combined cycle with co-firing of biomass (IGCC-CCS co-firing); Biomass integrated gasification combined cycle (BIGCC-CCS dedicated); Bio ethanol advanced generation and Biodiesel based on gasification and Fischer Tropsch-synthesis. Results of their analysis suggest that the potential for negative emissions are the largest for the dedicated biomass electricity generation routes with CCS with a net GHGs mitigation potential of −10.4 Gt/yr., followed by PC-CCS co-firing with CCS and IGCC-CCS both with −9.9 Gt/yr. emission reduction potential in 2050. The potential for negative emissions for biofuels production with CCS were the lowest, ranging between −1.1 and −6 Gt/yr. By conducting a techno-economic analysis, Klein et al. [20] concluded that BIGCC with CCS could serve as the main bioenergy conversion technology in the long-term, representing 33% of the global mitigation by 2100.

Among other BioCCS options, integrating CCS to a co-firing power plant is an attractive option because it is a well-established technology that allows current plants to be modified with fairly low investment cost. The fast growth of biomass co-firing plants, from 152 in 2007 to 241 in 2012 [21], is the result of the moderate investment needed for co-firing biomass in traditional coal fired boilers [22] and environmental benefits of the technology such as reduction of CO_2, SO_2 and, for some biomass types, also NO_x [23]. The Commission of European Commodities [24] suggested biomass co-firing as one of the most promising options for renewable energy based electricity generation and evaluated the technology

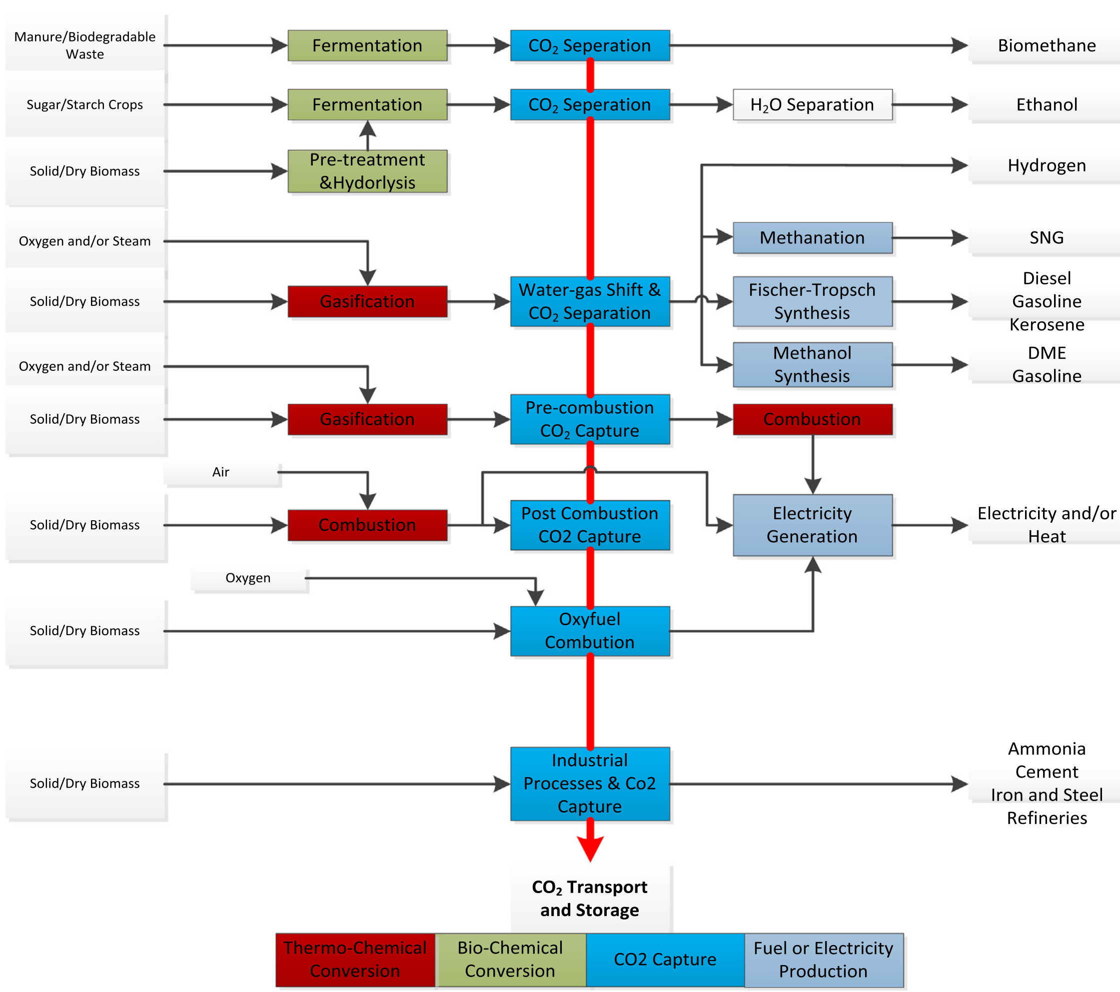

Fig. 1. Biomass use with CO_2 capture (BioCCS) integration options [12].