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Opportunities for application of BECCS in the Australian power sector

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HIGHLIGHTS

- BECCS in Australia has the potential to deliver 25 Mt CO_2/year negative emission.
- BECCS could supply up to 13.7 TW h electricity to the Australian power sector.
- Deployment of BECCS as a carbon negative strategy requires strong policy support.
- BECCS could enhance the flexibility and diversity of Australia's energy portfolio.

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ABSTRACT

Australia has committed to meeting its international obligations to decrease its greenhouse gas emissions including transitioning toward decarbonising its emission-intense energy sector. However, it is facing the dual problems of increasing electricity cost and decreasing energy security. One of the potential contributions to reducing its emission while supplying reliable power is deployment of bioenergy with carbon capture and storage (BECCS). BECCS is a carbon removal technology that offers permanent net removal of carbon dioxide from the atmosphere together with the prospect of negative emissions.

The present study was undertaken to assess the potential contribution of BECCS to achieving long term decarbonising of the Australian energy sector. This study considers the availability of sustainable bioenergy resources and the economic viability and environmental impacts of BECCS. In order to avoid the ecological uncertainties and social challenges of dedicated energy crops, this study focuses on organic waste from the municipal, agricultural, and forestry sectors. Based on the quantity of biomass resources available, BECCS options in Australia have the potential to remove a total of 25 million tonne CO_2/year from the atmosphere as negative emissions by 2050. In addition, BECCS systems could supply Australia with up to 13.7 terawatt-hours of renewable power by mid-century which is around 3.6% of expected gross electricity generation in 2050. Deployment of BECCS as a reliable supplier of electricity would potentially enhance the flexibility and diversity of Australia's energy portfolio and remove carbon dioxide from the atmosphere. However, deployment of BECCS as a carbon negative strategy will require strong policy support.

1. Introduction

A growing global consensus on mitigating anthropogenic greenhouse gas (GHG) emissions led to a historical agreement at the 2015 United Nations Conference of Parties (COP21) in Paris. This agreement sets out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2 °C [1]. Achieving this target demands strict emission reduction measures and tight emission budgets. The global budget for 2000–2050 is around 1700 Gt $CO_{2\text{-eq}}$ [2] but on current trends, the world is likely to overshoot this budget. According to the IPCC Fifth Assessment Report (AR5), over 100 of the 116 scenarios associated with concentrations between 430 and 480 ppm CO_2 ($< +2$ °C target) rely on removal of around 5–20 Gt $CO_{2\text{-eq}}$ annually, starting from mid-century [3–5]. A range of negative emission technologies (NETs) such as direct air capture and storage, ocean fertilisation, enhanced weathering of minerals, soil carbon sequestration and afforestation have been proposed [4,6–12]. Bioenergy with Carbon Capture and Storage (BECCS) is another negative emission technology that offers permanent net removal of carbon dioxide from the atmosphere. Using biomass for energy production is seen as carbon neutral, in that the carbon dioxide released to the atmosphere during energy conversion was first taken from the

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atmosphere during photosynthesis. However, in the case of BECCS, the CO_2 is not released to the atmosphere but is captured, transported and permanently stored in a suitable geological formation. In effect, a negative flow of CO_2 from the atmosphere to the subsurface is established.

A wide range of estimations of the NETs potential to remove atmospheric CO_2 can be found in the literature. Most of the studies suggest a higher negative emission potential for BECCS, afforestation (AR) and direct air capture (DAC) compared to other NETs [6–9]. According McLaren [9], BECCS with up to 10 Gt CO_2, AR with up to 3 Gt CO_2 and DAC with more than 10 Gt CO_2 offer the highest negative emission potential. A study by Smith et al. [6] showed a higher technical potential, up to 12 Gt CO_2 per year in 2100, for BECCS, AR and DAC. An estimation by Fuss et al. [8] confirmed this range, with BECCS, AR and DAC each having the highest negative emission potential of up to 12.1 Gt CO_2/year in 2100. Koelbl et al. [13] estimated that BECCS could offer 10 Gt CO_2/year negative emission in 2050 and around 20 Gt CO_2/year in 2100, which is several times the potential of AR (around 4 Gt CO_2/year).

1.1. Role of BECCS in achieving 2 °C target

BECCS is the most significant NET in integrated assessment models (IAMs) [14]. Unlike other NETs, BECCS offers the twofold advantage of delivering negative emission and providing carbon-free energy. Smith et al. [6] estimated the net energy potential of BECCS at around 170 EJ/year in 2100, whereas other NETs are net consumers of energy. Compared to other NETs, BECCS has the most immediate potential and already has pilot-scale demonstrations [7]. Another advantage of BECCS is the possibility of permanent CO_2 storage. The inherent susceptibility of terrestrial carbon stocks to disturbance such as wildfires (350 million hectares burnt per year globally [8]) makes sequestration by other land-based NETs such as afforestation and soil carbon sequestration less reliable [11].

The range of negative emission potentials of BECCS reported in the literature varies from zero to 20 Gt CO_2/year [11,15]. According to Gasser et al. [12], a "best-case" to achieve 2 °C target in addition to conventional mitigation, would require BECCS with annual negative emission of 1.8–11 Gt CO_2. In the recent International Energy Agency (IEA) global models, BECCS could deliver negative 14 Gt CO_2 between 2015 and 2050, of which 11 Gt CO_2 is captured from biofuels with CCS and 3 Gt CO_2 from dedicated and co-firing BECCS for power [16]. A study by Kemper [17] found the global technical potential of BECCS, through biomass gasification and direct combustion, to be around 10 Gt CO_2/year in 2050. Woolf et al. [18] estimated a lower global net negative emission of 3.3–7.5 Gt CO_2/year. Ricci and Selosse [19] used the multiregional TIAM-FR optimization model to assess the global and regional potential of BECCS. Their study showed that by 2050, BECCS and CCS could generate 23–30% of the electricity, equivalent to 5.7–7.6 Gt CO_2 captured and stored. Most of this capacity lies in developing countries, especially China, India and Brazil. In a complementary study, Ricci and Selosse showed that near-term widespread implementation of CCS with 15% BECCS would be a desirable way to achieve stringent emission targets [20]. In a study by Koornneef et al. [21], the economic potential of BECCS is estimated to be up to 3.5 Gt $CO_{2\text{-eq}}$/year negative emissions from the power sector and 3.1 Gt $CO_{2\text{-eq}}$/year in transportation. However, these potentials are not for the whole sectors but for the "best" routes, i.e. BIGCC-CCS and FT biodiesel in 2050. An assessment of the assumptions underpinning the feasibility of BECCS in IAM scenarios by Vaughan and Gough [22] showed that assumptions regarding technical aspects of BECCS is realistic. However, their results warned that the socio-political assumptions and future bioenergy potential for its large-scale deployment are unrealistic.

1.2. Global status of BECCS projects

Globally there have been twenty BECCS projects, mostly located in North America, Europe and Scandinavia [17,23,24]. Currently five of these projects are operating, capturing CO_2 from ethanol production plants with a total capacity range of 0.1–1 Mt CO_2/year negative emission [25]. Five projects have been cancelled mostly due to lack of economic viability and the remainder are either completed or under evaluations/planning [17]. The BECCS projects under planning use CCS coupled with a variety of bioenergy technologies such as waste-to-energy (in Norway and The Netherlands), ethanol plants (France, Brazil and Sweden), biomass combustion/co-firing (Japan), pulp and paper (2 projects in Sweden), biomass gasification (the U.S) and a biogas plant (Sweden) [15,17].

The large-scale deployment of BECCS took a major step forward in 2017, with the commencement of the Illinois Industrial CCS Project (IICCSP). The project has received US$140 million in capital support from the U.S Department of Energy and will also be able to access CO_2 storage credits of USD 20/t CO_2 [17]. IICCSP was established in 2011 [26]. In this project the CO_2 released during the fermentation process to produce ethanol at the Archer Daniels Midland (ADM) ethanol plant in Decatur, Illinois, is captured, transported and stored in a deep saline formation, the Mount Simon Sandstone [26]. During its operational period from November 2011 to November 2014, the IL-ICCS project injected 1 Mt CO_2 into the subsurface. Since 2017 the IIICCSP project has increased the CO_2 injection rate up to 1 Mt CO_2/year [26].

Recently a waste to energy agency in the Oslo municipality (EGE) conducted a feasibility study to assess the opportunities for CO_2 capture from a waste incineration plant at Klemetsrud [27]. Technical assessments show that the project could potentially capture up to 3.15 Mt CO_2 annually with a 90% CO_2 capture rate by 2020 [27]. Around 50–60% of this CO_2 is biogenic. Another project of this kind is ARV-Duiven in Duiven, in the Netherlands. The ARV-Duiven power plant with 70 MW capacity incinerates municipal solid waste (MSW) to produce around 126 GW h electricity. From 2018, ARV-Duiven is planning to capture up to 50 Kt CO_2 per annum using the MEA capture process [28].

1.3. Bioenergy and BECCS

Bioenergy required to provide the scale of BECCS projected in most IAMs is estimated to be in the range of 0–1000 EJ/year, with a high probability of around 100 EJ/year [17,29–36]. Kemper [17] addressed the lack of standard methodology and the likely effect of climate change as the main reasons for the large variations in estimating the global potential of bioenergy.

The challenge of scaling up bioenergy to the level required in 2 °C scenarios lies in producing sustainable biomass while maintaining a balance with essential food and fibre production. In addition, bioenergy expansion must act in accordance with technical and economic development, social expectations and policy/regulatory regimes [37]. Without this, intensification of bioenergy production, especially from energy crops, could result in severe competition between food, feed, and energy, leading to controversial economic, ethical, and environmental issues [15,38,39].

Expansion of bioenergy is constrained by its potential ecological ramifications. Historically, unsustainable biomass harvest has led to loss of a considerable proportion of natural forests and degradation of productive lands [29,34,40], increased GHG emissions, loss of biodiversity and carbon stock [41–47] and depletion of water resources [41–43,48]. Expanding bioenergy production must be carefully considered against the background of sustainability [49]. Two of the main environmental issues to be considered are land-use and water consumption; the area of land needed for bioenergy production depends on the productivity of the land, efficiency of production practices and the type of biomass. The area available for bioenergy production from energy crops in the literature is estimated to range from 80 to 2400 Mha [6,33,50–56]. However, the area required for forest, protected lands and human settlement leaves only 140 Mha available for bioenergy