BECCS (Bioenergy with Carbon Capture & Storage)

Sustainable Energy for the developing world Project

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Description

The Paris Agreement addressing climate change calls for a global response to reach peaking of greenhouse gas emissions and reduce the average temperature increase. However, in order to achieve negative emissions and reduce the cost of attaining these goals, more greenhouse gas emissions must be stored as compared to those released back into the atmosphere. It is for this reason that technologies such as BECCS should be used as mitigation tools in the case of carbon emissions, in order to decrease temperature change below 2 degrees.

Biomass energy, also known as bioenergy, is renewable energy generated from biological matter. The examples of bioenergy feedstock include energy crop, forest residue, agricultural residue, and bio-degradable matter. Carbon capture and storage (CCS) is a mechanism used to capture the CO_2 emissions from the combustion of fuels, while transporting and permanently storing the emissions in a location where they will not be reintroduced into the atmosphere. Although CCS is commonly applied to fossil fuels, it can also be applicable to biomass. The combination of bioenergy with CCS may present a viable approach to achieving net negative CO_2 emissions. This project report defines the parameters used to carry out a sustainability assessment study on biomass energy with carbon capture and storage (BECCS) technology using data from academic reports.

1. Technical overview

Bioenergy is the use of biomass to generate electricity or fuel for transportation. There are six major types of bioenergy systems: direct-fired, cofiring, gasification, anaerobic digestion, pyrolysis, and small, modular systems [1]. Most of the bioenergy plants in the world use direct-fired systems. In other words, they burn bioenergy feedstocks directly to produce steam.

The steam is used to turn a steam turbine and generate electricity. Other times, industries use the steam for different manufacturing processes or space heating. The use of wood waste to produce steam for paper mills while also generating electricity is an example of combined heat and power facilities [1].

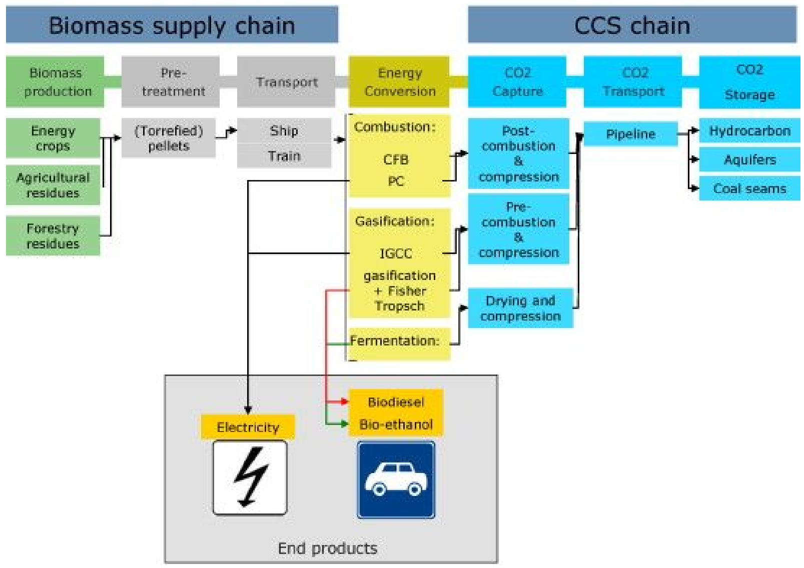

Fig 1 Steps in the bio-CCS routes [3]

Bioenergy feedstocks are carbon-based fuels and pose a challenge as the combustion of these fuels result in the emission of CO_2, which in excess is harmful to the environment. As shown in figure 1 above, there are three main approaches to capturing CO_2 [2]:

- In the pre-combustion capture, CO2 can be captured before combustion. This system involves reactions at high temperatures that result in gas with carbon monoxide, carbon dioxide and hydrogen. The CO2 is separated and capture while power is generated from burning the hydrogen. Hydrogen is considered a clean fuel that only produces water when burned. This method however, requires extensive modifications to existing power plants [10].
- When the CO2 is captured from gases after combustion this method is called post-combustion capture. The gases are separated and transported for storage. This

system is more costly and requires more equipment compared to the pre-combustion method. However, it is more easily adaptable for existing plants [10].

- In the case of oxyfuel combustion capture, almost pure oxygen is used. The result from the combustion is flue gas with CO2 and water. The system is similar to current combustion done in existing plants and can easily be utilized. The temperature required is much higher and therefore a custom boiler plus handling system is needed.

In regard to the available storage options, geological, ocean and terrestrial ecosystem storage are the approaches discussed in literature. The geological storage occurs when emissions are stored in saline aquifers with permeable rocks saturated with brine. On the other hand, ocean storage is when CO_2 emissions are captured and stored at depths where rapid release from oceans to the atmosphere is prevented. The storage of emissions in terrestrial ecosystem storage is determined by biogeochemical processes [2].

Finally, transporting CO_2 particularly in large scale plants is infrastructure intensive. As such, a large scale BECCS plant would require high investments in interconnecting transport infrastructure from capture to storage sites with marine and pipeline transport being the pervasive approaches to CO2 transportation.

2. The potential of BECCS

The International Energy Agency (IEA) estimates that 10 Gt of CO2 can be captured by BECCS plants annually in 2050 [11]. The ability to permanently store CO2 emissions will help combat the global warming phenomenal. Bio-energy can be classified as carbon neutral when viewed as an energy source that releases the same amount of carbon emissions that are captured during the lifetime of an organism/ plant. If the technology is deployed with appropriate regulations that ensure sustainable use of biomass to generate energy, the amount of GHG emissions in the atmosphere shall be reduced. The attainment of negative emissions can offset/ shift past effects and compensate for emissions in other sectors.

There were approximately 16 BECCS projects reported globally however none of these were commercialized plants. The BECCS is not a mature technology as it lacks sufficient research and development investments. To be cost effective, a facility has to be of a certain size to offset the CCS technology cost. Furthermore the potential emissions to be saved, or the value of the negative emissions also determines the size of the plant [5]. The following countries are included in the list of locations that have attempted to set up BECCS projects ; United States (Kansas, Texas, Illinois, North Dakota, Ohio, Washington), Netherlands, Sweden (Domsjo, Norrkoping, Skane), Brazil, France (Artenay), Germany (Ketzin), and Tanzania (Rufiji). The project in Illinois is currently the largest BECCS research project and is expected to inject 3,600,000 tonnes of CO2 into the ground [5].

3. Impact of BECCS implementation

To assess the economic, environment, and social impact of commercializing BECCS, results from several academic articles as well as institutional reports, were analyzed. Some of the current BECCS projects and predictive analytics from those who are exploring the technology have been evaluated in the section below.

Economic Impact

Cost of Electricity

In order to assess the effect on the cost of electricity when BECCS is implemented, three studies were compared. The functional unit used for the LCOE calculations was kWh. Assuming 7% discount rate and 40 year lifetime, the CRF was calculated.

The capacity factor (CF) for biomass and coal was assumed to be similar to the CF of BECCS, and estimated to be 80% [7]. The assessment compared the cost of electricity among coal, biomass, and BECCS plants.

LCOE = (capital cost * CRF)/ annual generation + (O&M)/annual generation

	Capital cost ($/kW)	O&M ($/kW)	CRF	CF (%)	LCOE ($/kWh)
Low co-firing (Coal + biomass)	150	104	0.075	80	**0.016**
Biomass	640	116	0.075	80	**0.023**
Biomass + CCS	1528	168	0.075	80	**0.040**

Table 1 Results from LCOE calculation [7]

The variable operation and maintenance (O&M) costs for BECCS were calculated by adding the MEA (Monoethanolamine) cost of CCS and the cost of handling CO2 for every KWh of electricity as reported in [7].

Based on the LCOE results, the implementation of CCS with bioenergy will increase the cost of electricity. This may result in issues of affordability due to the expensive nature of the technology.

Environmental Impact

The deployment of BECCS technology on a large scale can either be positive or negative depending on the regulations and policies that are put in place. On a positive note, BECCS can result in reduction of CO2 emissions and compensate for technologies with high emissions. However, when implemented against weak regulations and unsustainable use of biomass, the technology can encourage direct and indirect land use change.

Net negative emissions

While accessing the lifecycle emissions for BECCS, the kWh was chosen as the functional unit. All emissions were reported in g of CO2 equivalent per kWh.   Based on the information provided in table 2 below, the use of biomass with CCS can result in negative emissions. However, the emissions reported do not take into account emissions from land use change.

	g CO2 equivalent/ kWh

Co-firing ratio	Farmed trees		Switchgrass		Forest residue	
	Without CCS	With CCS	Without CCS	With CCS	Without CCS	With CCS
0%[1]	893	143	893	143	893	143
5%	861	90	864	93	862	77
10%	825	34	829	41	829	9
15%	783	-22	790	-12	785	-60
20%	742	-79	751	-65	744	-130
100%[2]	61	-1449	121	-1345	7.9	-1818

Table 2 : GHG life-cycle emission rate for biomass co-firing without CCS and with CCS [7]

[1] reference purely coal-fired power plant

[2] Retrofitted for purely biomass power plant

Land use change (LUC)

As mentioned earlier, bioenergy is said to be carbon neutral. However, carbon neutrality is only valid for countries which account for land use change (LUC) in their inventories. The shift from food to energy crops will result in direct and indirect land use change. Direct land use change (LUC) is the displacement of food crop for bioenergy agriculture while indirect land use change (ILUC) results from deployment of bioenergy crops were displaced fraction of food crops are planted elsewhere on the globe. Once farmers change their land use behavior and begin to plant energy crops in areas previously used for growing food, this could result in effects that negate the greenhouse gas savings resulting from BECCS.

As earlier discussed BECCS requires additional land use. During clearing of land, there are significant carbon losses. As such on a large-scale, the LUC emissions could be significant. Achieving low carbon projections should take into account the implications of land use change as deploying large scale BECCS could negate the CO2 sequestration by BECCS [16].

Social Impact

Implementing BECCS on a large scale will lead to several social impacts which include but are not limited to market effects, and employment

Global food prices (market effects)

The conversion of food croplands to energy croplands means that in the earlier stages of this transition, food supply would reduce, as a consequence food prices would increase. In addition, other wise uncultivated lands could be utilized to meet the demand for food at the high price. Some of the effects of this includes the inability of poor people to afford food particularly non-agrarian citizens, reduced poverty as a result of increased income in rural areas, and increased demand for or dependence on animal food. According to Mueller, S et.al three out of four studies on the impact of biofuel use on food prices concluded that biofuel production had a modest (3–30%) contribution to global commodity food prices [4]. Perhaps the biggest argument against bio energy is the 'food for fuel' metaphor for which its proponents posit that diverting crop consumed as food to fuel would lead to increased hunger. Subsidies for biofuels worsens the situation as the increased demand for these food crops like corn and oil (palm oil, rapeseed oil) in the energy sector typically leads to hike in prices of these crops. In other words an average consumer (for feeding purposes) would scarcely be able to afford the crops.

Employment

As discussed earlier, bioenergy power plants relies heavily on biomass feedstock. Supply has to match the rise in demand for these feedstock with the introduction of a BE plant. As such, labour would be needed in the cultivation, processing, and transportation of these biomass feedstock. The Brazilian sugarcane ethanol industry is reported to employ six times more workers than the country's petroleum sector. Furthermore, the workers receive higher incomes compared to other agricultural sectors. The introduction of BECCS technology thus presents new opportunities for employment. In addition, new skills would need to be developed in order to meet the human capacity or labour requirements of the technology. A positive social impact of the technology is thus the promotion of the development of new skills. In a skill rewarding economy - one characterized by the potential of getting more lucrative jobs by having an in demand skill - the standard of living of these newly skilled workers would potentially improve.

4. Challenges in deploying BECCS on a large scale

The commercialization of BECCS on a large scale has not occurred due to various challenges. Some of the constraints faced in the deployment of the technology are discussed below.

Uncertainty

The uncertainty of biomass supply as well as the duration of carbon storage renders the technology financially risky. The technology is immature and has not been adequately researched. There is still uncertainty regarding the number of years the injected CO2 will remain stored in the ground.

Unsustainable use of biomass

The adoption of this technology, will require large scale bioenergy production which may result in unsustainable use of biomass. Without adequate policies and regulations, deforestation may result from the need to supply BECCS power plants. This will reverse the expected progress in achieving negative emissions. The public perception that large scale bioenergy production will result in unsustainable use of biomass leads to resistance in commercializing the technology.

Energy Overhead of CCS

Well known as the energy penalty; separating, compressing and transporting the CO2 over pipelines requires a considerable amount of energy. Various studies on the energy penalty of capturing CO2 and reports the energy penalty of Integrated coal Gasification Combined Cycle (IGCC) power plants (six studies) as 9%, Pulverized Coal (PC) power plants (four studies) at 15%, and Natural Gas Combined Cycle (NGCC) power plants (four studies) at 10% [15]

Carbon tax and CO2 avoidance cost

The CO2 avoidance cost reflects the cost of reducing CO2 emissions while producing the same amount of product from a reference plant often regarded as a carbon tax [6]. CO2 avoidance cost can be affected by the choice fuel, thus the challenge in addition to efficiency constraints is the determinant and availability of a biofuel that would lead to low CO2 avoidance costs.

5. Recommendations for the pathway to sustainability

The use of unsustainable methods to generate biomass energy may negate the positive effects of implementing BECCS. Taking into account land ownership, water for food production and energy crop competition, the success involved in up-scaling this technology relies heavily on the sustainability of the methods used.

- Regulations and policy

In order for BECCS projects to succeed, countries must provide a conducive environment for investment in further research and development. Additionally, incentives for developers will increase the likelihood of private participation which will encourage commercialization.

- Carbon tax

Currently, it is difficult to measure negative emissions from BECCS. With a carbon tax applied and accountability models that take into consideration the emission savings, this technology can be more feasible.

- Profitability

In order to achieve profitability, business models for BECCS plants are commonly based around utilizing the captured CO_2 for Enhanced Oil Recovery (EOR). If BECCS is combined with EOR, the net life cycle emission effect becomes non-negative, as a result of the fossil emissions from the extracted oil. However, the emissions are reduced significantly by combining EOR with BECCS rather than with other oil extraction methods [5].

- Managed forestry

Sustainable forest management involving proper maximization of the benefits available from forests and could aid the the carbon sink capacity of forests. The adverse effects of unmanaged forestry ranges from wildfires to loss of jobs and disease and insects. Managing requires the creation and implementation of strategies and plans that ensures the protection and resilience of forests while harnessing the potential to meet anthropogenic needs.

- Competitiveness of BECCS

Through Bio Synthetic Natural gas (Bio-SNG) production, BECCS can be a competitive alternative compared with fossil fuel fired power plants and CCS due to its relatively low CO2 avoidance cost. [12] further posits after analysis that RCP (Representative concentration pathways) 2.6 could be achieved if a post combustion CO2 capture system and high-fertilizer application were fully utilized [12]. RCP 2.6 is a projection of the global warming increase by the fifth assessment report of the IPCC.

	2046-2065	2081-2100
Scenario	Mean and likely range	Mean and likely range
RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)

Table 3: RPC 2.6 [13]

6. Conclusion

In conclusion although BECCS has the potential to achieve net negative emissions, there constraints and challenges in commercializing the technology. Below is a summary of the results from the technology assessment presented in this report.

Bioenergy is the generated from biological matter and feedstock such as forest residue, energy crop, agricultural residue, and bio-degradable matter are burned to release energy, The CCS technology is the process of capturing CO2 emissions for storage to prevent re-entry into the atmosphere. BECCS is a combination of bioenergy production with carbon capture and storage technology. Although there some projects in the exploration phase across the globe, none of these plants have been commercialized.

According to IEA, BECCS has the potential to inject 10Gt of CO2 into the ground by 2050. The technology can be used to achieve net negative emissions and compensate for other sectors failing to cut back on emissions.

Economically, BECCS is expensive and the implementation of this technology will result in the increase of the levelized cost of electricity. As seen in the section 3, electricity generated from BECCS plants shall be more expensive as compared to biomass and coal power plants.

The BECCS technology has both positive and negative environmental impacts. While the implementation of this technology will result in reduced carbon emissions, there is a risk associated with land use changes. The demand for biomass for large scale electricity and biofuel production will a shift from food crop growth to energy crop cultivation. The food crop shall in turn be grown in a different location. These direct and indirect land use changes are difficult to measure however, they minimize the positive effects of the BECCS deployment.

There various social effects that may be associated with large scale adoption of BECCS. These include but are not limited to job creation, attainment of new skills, and market effects such as increase in food prices.

The deployment of this technology has been slow due to challenges such as uncertainty, unsustainable use of biomass, lack of affordability and profitability. There is the aspect of public perception which has led to the cancellation of BECCS projects in places like Washington, DC, US.

In assessing the BECCS for large scale and commercialized implementation, the recommendation is to put regulations and policies in place that enable the growth of this technology. There is a need for carbon tax in order to account for the net negative emissions during the operation of BECCS plants. Options such as co-firing should be put on the table to increase efficiency and reduce emissions in existing coal plants. Furthermore strategies for managed forestry must be put in place to prevent unsustainable use of biomass or deforestation.

References

[1] Biopower. (n.d.). Retrieved November 29, 2016, from http://www.renewableenergyworld.com/bioenergy/tech/biopower.html

[2] Rackley, S. (2009). *Carbon capture and storage*. Gulf Professional Publishing.

[3] Koornneef, J., van Breevoort, P., Hamelinck, C., Hendriks, C., Hoogwijk, M., Koop, K., ... & Camps, A. (2012). Global potential for biomass and carbon dioxide capture, transport and storage up to 2050. *International Journal of Greenhouse Gas Control*, *11*, 117-132.

[4] Mueller, S. A., Anderson, J. E., & Wallington, T. J. (2011). Impact of biofuel production and other supply and demand factors on food price increases in 2008. Biomass and Bioenergy, 35(5), 1623-1632.

[5] Biorecro, A. B. (2010). Global Status of BECCS Projects 2010. *Canberra, Australia: Global CCS Institute*.

[6] Simbeck, D., & Beecy, D. (2011). The CCS paradox: the much higher CO 2 avoidance costs of existing versus new fossil fuel power plants. *Energy Procedia*, *4*, 1917-1924.

[7] Cuellar, A. D., & Herzog, H. (2015). A path forward for low carbon power from biomass. *Energies*, *8*(3), 1701-1715.

[8] Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J., ... & Yu, T. H. (2008). Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science*, *319*(5867), 1238-1240.

[9] Global CCS Institute, 2014. "Modelling Bio-sequestration to Reduce Greenhouse Gas Emissions", [Online]. Available: http://hub.globalccsinstitute.com/sites/default/files/publications/147933/modelling-bio-sequestration-reduce-greenhouse-gas-emissions.pdf.

[10] E. Edström and C. Öberg, "Review of Bioenergy with Carbon Capture and Storage (BECCS) and Possibilities of Introducing a SmallScale Unit", KTH Industrial Engineering and Management, 2016. [Online]. Available: http://www.diva-portal.se/smash/get/diva2:633335/FULLTEXT01.pdf

[11] J. L. Milne and C. B. Field, "Assessment Report from the GCEP Workshop on Energy Supply with Negative Carbon Emissions", Global Climate and Energy Project, 2016. [Online]. Available: https://gcep.stanford.edu/pdfs/rfpp/Report%20from%20GCEP%20Workshop%20on%20Energy%20Supply%20with%20Negative%20Emissions.pdf

[12] Carbo, M. C., Smit, R., van der Drift, B., & Jansen, D. (2011). Bio Energy with CCS (BECCS): Large potential for BioSNG at low CO 2 avoidance cost. Energy Procedia, 4, 2950-2954.

[13]"Representative Concentration Pathways - Wikipedia." 2016. Accessed December 2. https://en.wikipedia.org/wiki/Representative_Concentration_Pathways#CITEREFIPCC_AR5_WG12013.

[14] R. Tidball, N. Rodriguez and S. Knoke, "Cost and Performance Assumptions for Modeling Electricity Generation Technologies", National Renewable Energy Laboratory, 2016. [Online]. Available: http://www.nrel.gov/docs/fy11osti/48595.pdf.
[15] David, J., & Herzog, H. (2000, August). The cost of carbon capture. In fifth international conference on greenhouse gas control technologies, Cairns, Australia (pp. 13-16).
[16]Kato, E. and Yamagata, Y. (2014), BECCS capability of dedicated bioenergy crops under a future land-use scenario targeting net negative carbon emissions. Earth's Future, 2: 421–439. doi:10.1002/2014EF000249
[17] Satolo, L., & Bacchi, M. (2013). Impacts of the recent expansion of the sugarcane sector on municipal per capita income in São Paulo state. *ISRN Economics*, *2013*.