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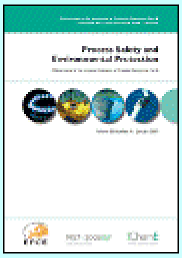

Tuomas Mattila, Juha Grönroos, Jachym Judl, Marja-Riitta Korhonen. ***Is biochar or straw-bale construction a better carbon storage from a life cycle perspective?*** **Pages 452–458.**

Biochar has been presented as a key technology for avoiding dangerous climate change. Pyrolysis converts part of the biomass feedstock into a gaseous fraction, which can be used for energy production. The remaining fraction is char, which is highly stable and resistant to biodegradation. When char is added to soil it increases carbon storage, reduces emissions and improves soil quality. Agricultural residues such as straw, stover and hulls are seen as the most accessible raw material. These residues could also be used as insulation in passive energy housing. Straw bale construction is a relatively simple technology, which has been applied for decades. It can store the carbon of the straw material into walls structures and in the process provides energy efficient housing. The climate benefits from improved energy efficiency depend on local conditions and energy production forms. In this study life cycle assessment was used to compare the climate impacts of biochar production and straw bale construction. On a life cycle perspective, straw bale construction results in higher net carbon storage than biochar production (3.3 t CO_2eq vs. 0.9 t CO_2eq/t of straw). However the result was found to be highly dependent on the assumptions on the overall energy efficiency of the replaced building stock.

- **Keywords:** Carbon storage; Straw; Pyrolysis; Natural building; Life cycle assessment

J.-F. Boucher, P. Tremblay, S. Gaboury, C. Villeneuve. ***Can boreal afforestation help offset incompressible GHG emissions from Canadian industries?*** **Pages 459–466.**

To mitigate greenhouse gas and comply with cap-and-trade systems, the carbon capture and storage (CCS) is presently unviable for industrials dealing with low concentration of CO_2 emissions. Alternatively, a new offset opportunity is being analysed in Canada: the afforestation of open woodlands (OWs) in the boreal territory. The results obtained from model simulations (with CBM-CFS3) showed that afforestation of boreal OWs can be a low C-intensive mitigation activity, in particular when understory planting is the chosen silvicultural approach, so that only 8–12 years are needed to reach a net positive C balance with the afforestation of OWs. A large-scale afforestation of boreal OWs – scheduled at 20 kha per year during 20 years for a maximum of 400 kha – could provide capped industrials with a significant offset potential, for instance up to nearly 8% offset of all Québec industrial process emissions (2009 data) after 45 years. In spite of a certain number of issues that can contribute to the uncertainty of the real environmental

and economical benefits from the afforestation of OWs as a mitigation activity – most of which issues are discussed in this paper – this study presented a first glimpse at the extent to which the afforestation of boreal OWs in Québec can provide large emitters with eventually substantial and efficient GHG offset potential, especially those emitters tied up with incompressible GHG emissions.

- **Keywords:** Afforestation; Boreal forest; Climate change; GHG emissions; Mitigation; Smelters

Antoine de Ramon N'Yeurt, David P. Chynoweth, Mark E. Capron, Jim R. Stewart, Mohammed A. Hasan. *Negative carbon via Ocean Afforestation.* Pages 467–474.

Ocean Afforestation, more precisely Ocean Macroalgal Afforestation (OMA), has the potential to reduce atmospheric carbon dioxide concentrations through expanding natural populations of macroalgae, which absorb carbon dioxide, then are harvested to produce biomethane and biocarbon dioxide via anaerobic digestion. The plant nutrients remaining after digestion are recycled to expand the algal forest and increase fish populations. A mass balance has been calculated from known data and applied to produce a life cycle assessment and economic analysis. This analysis shows the potential of Ocean Afforestation to produce 12 billion tons per year of biomethane while storing 19 billion tons of CO_2 per year directly from biogas production, plus up to 34 billion tons per year from carbon capture of the biomethane combustion exhaust. These rates are based on macro-algae forests covering 9% of the world's ocean surface, which could produce sufficient biomethane to replace all of today's needs in fossil fuel energy, while removing 53 billion tons of CO_2 per year from the atmosphere, restoring pre-industrial levels. This amount of biomass could also increase sustainable fish production to potentially provide 200 kg/yr/person for 10 billion people. Additional benefits are reduction in ocean acidification and increased ocean primary productivity and biodiversity.

- **Keywords:** Reversing climate change; Marine agronomy; Carbon capture and storage; Negative emissions, Ocean Macroalgal Afforestation (OMA); Algae biofuel

Phillip Williamson, Douglas W.R. Wallace, Cliff S. Law, Philip W. Boyd, Yves Collos, Peter Croot, Ken Denman, Ulf Riebesell, Shigenobu Takeda, Chris Vivian. *Ocean fertilization for geoengineering: A review of effectiveness, environmental impacts and emerging governance.* Pages 475–488.

Dangerous climate change is best avoided by drastically and rapidly reducing greenhouse gas emissions. Nevertheless, geoengineering options are receiving attention on the basis that additional approaches may also be necessary. Here we review the state of knowledge on large-scale ocean fertilization by adding iron or other nutrients, either from external sources or via enhanced ocean mixing. On the basis of small-scale field experiments carried out to date and associated modelling, the maximum benefits of ocean fertilization as a negative emissions technique are likely to be modest in relation to anthropogenic climate forcing. Furthermore, it would be extremely challenging to quantify with acceptable accuracy the carbon removed from circulation on a long term basis, and to adequately monitor unintended impacts over large space and time-scales. These and other technical issues are particularly problematic for the region with greatest theoretical potential for the application of ocean fertilization, the Southern Ocean. Arrangements for the international governance of further field-based research on ocean fertilization are currently being developed, primarily under the London Convention/London Protocol.

- **Keywords:** Geoengineering; Negative emission technologies; Ocean fertilization; Iron; Southern Ocean; Governance

Duncan McLaren. ***A comparative global assessment of potential negative emissions technologies.*** **Pages 489–500.**

The paper summarises a global assessment of around 30 prospective negative emissions techniques (NETs) found in the literature. Fourteen techniques including direct air capture, BECCS, biochar, and ocean alkalinity enhancement are considered in more detail.

The novel functional categorisation of NETs developed in the course of the assessment is set out and a comparative quantitative summary of the results is presented, focusing on the relative readiness, global capacity, costs and side-effects of the prospective NETs.

Both technology specific and more generic potential limitations are discussed, notably those arising from energy requirements, from availability of geological storage capacity and from sustainable supply of biomass.

Conclusions are drawn regarding the overall scope of NETs to contribute to safe carbon budgets, and challenges arising in the future governance of NETs, with particular reference to the potential role of carbon markets.

- **Keywords:** Negative emissions; Direct air capture; Bioenergy with CCS; Carbon storage

Niall McGlashan, Nilay Shah, Ben Caldecott, Mark Workman. ***High-level techno-economic assessment of negative emissions technologies.*** **Pages 501–510.**

This paper presents results from research conducted to provide a high level techno-economic and performance assessments of various emerging technologies for capturing CO_2 from the air, directly and indirectly, on a life-cycle basis. The technologies assessed include 'artificial trees', the soda lime process, augmented ocean disposal, biochar and bio-energy with carbon capture and storage.

These technologies are subjected to quantitative and qualitative analyses, based on the most recent peer reviewed data in the literature, to identify their potential performance as well as the technical and non-technical barriers to their adoption and scale up. Key findings for each technology are presented which seek to highlight the state of technological development and research needs, the anticipated life cycle capture cost in $/tCO_2 based on their potential to deliver a 0.1 ppm CO_2 reduction per annum, policy requirements for scale up and, in light of these findings, the likely role that they will play in addressing climate change and broader environmental issues in the medium to long term.

The key finding from the work is that the degree of scale-up required for negative emissions technologies to have a material impact on atmospheric emissions (i.e. at a ppm level) is probably unrealistic in less than 20 years. Therefore, emissions prevention efforts should remain the main focus in addressing climate change and the likely role for negative emissions technologies will be in augmenting a suite of mitigation measures targeting economically or practically difficult emissions.

- **Keywords:** Techno-economic; Artificial trees; Soda lime; Augmented ocean disposal; Biochar; Bio-energy with carbon capture and storage