Estimating N_2O emissions from Ocean Afforestation
Supplementary Information for "Negative Carbon via Ocean Afforestation"

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By Mark E. Capron, PE, PODenergy

Any production of N_2O is adverse for two reasons: It has about 300 times the warming potency per gram relative to 25 times for CH_4 and 1 for CO_2. Plus, N_2O causes ozone depletion. However, it is beneficial as an additional source of energy during combustion with a fuel such as CH_4. N_2O emissions from agricultural operations, industrial, and fossil fuel combustion with air contribute to climate change. Any incidental N_2O emissions should be subtracted from the other benefits of Ocean Afforestation.

Microbes produce N_2O in nature and one should expect N_2O emissions from Ocean Afforestation like any other ecosystem. Humans are still learning how conditions affect N_2O production. Human managed biologic processes for converting N_2O to less harmful molecules are being developed, but conversion is likely happening coincident with any biologic N_2O generation.

In short, the potential for N_2O emissions from any step in the ecosystem should be investigated further. A quick review of the literature suggests N_2O emissions can be insignificant or significant depending on how the processes in the Ocean Afforestation ecosystem are arranged.

Human managed processes emitting N_2O include composting and treating wastewater. N_2O is produced in wastewater treatment plants in small amounts as NH_4 is converted to NO_3 with plenty of dissolved oxygen (aerobic zone) and NO_3 is converted to N_2 in the absence of dissolved oxygen (anoxic zone). The common wastewater treatment process cycles wastewater through alternating exposures of dissolved O_2 in excess of 4 mg/L followed by dissolved oxygen much less than 1 mg/L. However, Ahn, et al. (2010) discovered more N_2O was released from the anoxic zone than from the aerobic zone and the N_2O emissions ranged from 0.01% to almost 2% of the N_2 emissions.

Based on limited knowledge, the N_2O emission possibilities for steps in the Ocean Afforestation Ecosystem are as follows:

Growing – Provided dissolved oxygen is present above about 4 mg/L, bacteria will not be converting the NO_3 to N_2 or N_2O. This concept derives from Fagerstone, et al. (2011) research concerning N_2O emissions from two types of microalgae-for-fuel operations. One type was covered without oxygen in contact with the water. The other type was a pond open to the atmosphere. During the day, algae produce dissolved O_2 and there was no N_2O production in either system. At night, there was N_2O production from the enclosed systems but not the systems open to air. The enclosed systems had very low dissolved oxygen at night. These findings and research on wastewater treatment operations suggest the Ocean Afforestation design should avoid accumulating masses of decaying macroalgae in a low-oxygen environment with significant NO_3.

Harvesting – It is best to harvest when dissolved O_2 is low so that biomass is not aerobically digested, or to retain the water containing dissolved CO_2 that results from aerobic digestion. Aerobically digested biomass is not available for CH_4 production. On the other hand, it would be best to move the harvested biomass from sea surface to container interior while the mass has relatively low NO_3 or NH_4 concentrations or fast enough to avoid N_2O production.

Digesting – N_2O may be produced in the digestion container proportional to the NO_3 in the water with any N_2 production. Any N_2O coming off as a gas will be captured and combusted with the methane. N_2O is an additional energy source as it supports combustion and releases energy while converting to N_2 at internal combustion engine temperatures. Therefore there will be no GHG impact from the N_2O that exits the digester directly as gas.

The question is, "How much N_2O will remain dissolved in the liquid digestate after digestion and all the CH_4 and N_2O gases have been removed, and the digestate is ready to distribute to nourish the growing macroalgae?" This remnant of N_2O might escape to the atmosphere, if it is not converted to N_2 before it can escape the water.

We could not find studies indicating the proportion of N_2O in wastewater treatment plant biogas, which may be a similar situation to the OMA containers of macroalgae. It likely varies with the NO_3 concentration and most of the NO_3 will convert to N_2. Wastewater treatment plants monitor H_2S in their biogas. Typical H_2S concentrations range from 50 to 1,000 mg/L (0.1 %). Typical N_2 concentrations range from 1-2%. Because introduced NO_3 has only one step for conversion to N_2, the fraction of incidental N_2O is likely less than the low end (0.05% of the N_2 production) of the range listed in Ahn, et al. (2010). That implies N_2O production less than 0.001% of the total gas production. That implies the N_2O production is about .000025 of the CO_2 production with anaerobic digestion at 1 atm. Or 0.025 kg (~8 kg CO_{2e}) for every ton of CO_2 or less than 1% of the CO_2 capture.

When employing the differential dissolution process, the gases which had been dissolved at depth are captured after bubbling out of solution at the ocean surface or 1 atmosphere of pressure. (See the supplemental data "OMA Process Concepts" for additional gas recovery techniques.) The gases in the capture container over the liquid will have partial pressures about 0.1 atm for CH_4, about 0.9 atm for CO_2. But what is the likely partial pressure for N_2O?

CH_4 dissolves to 0.023 gm/L at equilibrium under one atmosphere of pure CH_4. N_2O and CO_2 both dissolve to about 1.5 gm/L under pure N_2O or CO_2 at one atmosphere. The N_2O will be concentrated by the differential dissolution just like the CO_2 is concentrated. The remnant of N_2O still dissolved after most previously dissolved gases are trapped in the capture container might be released when the nutrients are recycled.

Nutrient Recycling – If there is some non-accidental release of N_2O from anaerobic digestion, it would be mixed with that dissolved CH_4 and CO_2 which does not come out of the liquid digestate as gas bubbles when the digestate is at one atmosphere pressure exposed to the captured CO_2 and other gases.

If the captured dissolved CO_2 and N_2O gases are in about the same proportions as their production, the N_2O partial pressure might be ~0.00003 atm. An approximate calculation of N_2O potential emission from the post-capture treatment facility[1] is as follows:

1.5 kg/m^3 dissolved N_2O/atm * 0.00003 atm * 9,000 m^3 of water per day = 0.4 kg/day of N_2O

The 0.4 kg/day of N_2O (120 CO_{2e}/day) is 0.02% of the 700,000 kg/day of captured bio-CO_{2e}/day. N_2O from anaerobic digestion would only have offset 0.02% of the sequestered CO_2. (Note this result is preliminary and requires further study. Many controllable parameters can change N_2O

[1] The supplemental data "Process Concepts" explains post-capture treatment facilities converting NH_4 to NO_3 and CH_4 to CO_2 and H_2O.

emissions substantially: the biomass dry solids fraction in the digester; the digester input biomass NO_3 concentrations, etc.)

Summary – Based on available research it appears that total N_2O emissions to the atmosphere from the proposed Ocean Afforestation ecosystem will be measureable but not significant relative to the CO_2 stored.

However, Ocean Afforestation ecosystem design has many opportunities for innovation. We are fore-warned to consider N_2O emissions and know to favor ecosystem arrangements emitting less N_2O than others. Arrangements emitting less N_2O may have an economic advantage when selling CO_{2e} removal and storage. For example, we might remove the N_2O from the nutrient recycling step by sucking the on-site electricity combustion air through head-space over the post-capture treatment facility.

References

Ahn, J. H., Kim, S., Hongkeun, P., Rahm, B., Pagilla, K., and Chandran, K. (2010) N_2O Emissions from Activated Sludge Processes, 2008-2009: Results of a national Monitoring Survey in the United States, Environ. Sci. Technol., 44, 4505–4511.

Fagerstone, K.D., Quinn, J.C., Bradley, T.H., De Long, S.K., Marchese, A.J. (2011) Quantitative Measurement of Direct Nitrous Oxide Emissions from Microalgae Cultivation, Environ. Sci. Technol. 45, 9449-56.