BEAM*2022—measuring biosolids impacts on climate change and resiliency

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ABSTRACT | How water resource recovery facilities (WRRFs) manage their "waste" solids can have a major impact on their carbon emissions. This article discusses an updated greenhouse gas calculator, the biosolids emissions assessment model (BEAM*2022), that can be used to estimate carbon emissions from up to 10 biosolids management options. It reviews carbon accounting, how BEAM*2022 was developed, how it works, and what it can be used for. The model is highly recommended for planning, and it can be customized for local utility conditions. BEAM*2022 can inform WRRF decision-makers about more sustainable biosolids management processes, which can have major impacts on carbon emissions and be integral to climate change solutions that are desperately needed.

KEYWORDS | Climate change, greenhouse gas emissions, biosolids management, carbon accounting, long-term planning

The biosolids-climate change nexus fits under the larger water-energy nexus. It takes a lot of water to make energy and a lot of energy to make clean water, so clean water professionals may have a greater responsibility to do whatever we can to reduce the impact we have on the climate. We need to find any way to reduce energy and water demands by water resource recovery facilities (WRRFs), reduce our utility's greenhouse gas (GHG) emissions, and improve resiliency. Biosolids management (treatment and end use) contributes a significant proportion of GHG emissions from WRRFs. Mitigating climate change requires major reductions in carbon emissions. How we manage our biosolids can definitely be part of the solution.

Biosolids are an endlessly renewable resource. Recycling them is not the cheapest or easiest solution, but we do so to enhance soil health, recycle nutrients, reduce fertilizer and pesticide use, and strengthen farm economies. Biosolids-based soil amendments also provide micronutrients such as zinc, iron, manganese, and copper that healthy soils need and that are not found in other products. Biosolids put carbon back in the soil and have been shown to help with carbon sequestration and drought tolerance. The concerns with biosolids will always be there: odors, over-application of nutrients, and, of course, trace contaminants like per- and polyfluoroalkyl substances (PFAS) and others addressed in the past.

WRRFs should understand the impacts their biosolids management decisions have on carbon emissions. Working within communities, where the wastewater solids are generated, WRRFs should decide what is the "highest and best use" of those materials—not looking at these materials as waste, but as resources to recover.

ACCOUNTING FOR CARBON FROM BIOSOLIDS MANAGEMENT

The North East Biosolids & Residuals Association (NEBRA) has a new Carbon Trading Committee interested in carbon accounting for biosolids management programs. This committee has already learned much about carbon offset trading programs from guest speakers and experts. It plans to evaluate current methodologies and carbon credit protocols that have been implemented, find where biosolids and residuals can fit into the system with beneficial reuse projects, and help NEBRA members develop carbon trading projects. The committee will also oversee the roll out and annual review of the updated 2022 biosolids emissions assessment model (BEAM*2022), making sure BEAM*2022 is up-to-date, with the goal of making it acceptable for regulatory and voluntary carbon trading programs. This GHG calculator will be available online.

Carbon accounting refers to measuring or *modeling* and validating carbon emissions and *reductions*. This involves accounting-type activities such as inventories and audits. Models help here since measuring carbon emissions or reductions in the field for every project is not feasible. Measuring or modeling our carbon emissions from various biosolids management practices will highlight the most impactful actions or areas to address and can lead to meaningful changes.

In the western United States, especially in California, Oregon, and Washington, a concerted effort is ongoing to maximize the benefits of biosolids. They are used extensively in agriculture, as well as in silviculture and forestry, and for restoring fire-ravaged lands, with much research showing how biosolids-based soil amendments improve poor soils. King County (Seattle, Washington area) is using carbon accounting through its own adaptations of the original BEAM, which was published by the Canadian Council of Ministers of the Environment (CCME) in 2009. The county is also conducting research into the longevity of climate impact from recycling biosolids. Its strategic plan for biosolids focuses on recycling. The climate action plan of San Francisco Public Utilities also includes biosolids recycling, driven in part by California's ban on disposing of organic materials—including biosolids—in landfills.

Numerous states in the Northeast have completed or are working on climate action plans. Vermont, for example, published its climate action plan in December 2021; it focuses on five "impact areas," including climate pollution, carbon capture, resilient working and natural lands, vital communities, and cross-cutting solutions. As recognized and supported throughout the western United States, recycling biosolids meets those criteria.

BEAM*2022—A USEFUL TOOL

NEBRA is excited to manage BEAM*2022, a GHG calculator related to biosolids processing and end use and disposal. This new, updated version was recently launched on a new website (biosolidsdGHGs.org). BEAM*2022 is an elaborate spreadsheet, using formulas and emission factors to calculate—in accounting terms—carbon debits (emissions) and credits (sinks). BEAM*2022 focuses on the major greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Methane and nitrous oxide have much higher global warming potential (25 times and 298 times more than carbon dioxide, using the International Panel on Climate Change

Screenshot from the new website—biosolidsdGHGs.org

[IPCC] AR4 factors that EPA still relies on). The BEAM*2022 calculations are consistent with and use other emissions factors based on IPCC protocols. The new BEAM*2022 is available as a public service (subscriber-donation model). The objective is to offer a consensus-driven, standardized tool that utilities can use to compare carbon emissions from a range of current or potential future biosolids management scenarios to help inform their decision-making.

HISTORY OF BEAM*2022

The original BEAM was developed for the CCME by a consortium of well-known experts in the biosolids field. According to the original 2009 CCME *User Guide*, the BEAM model was developed to allow operators, engineers, and managers to assess potential GHG emissions from a range of biosolids management scenarios. The model can be used for the following:

- Estimating a program's GHG emissions, including establishing a baseline
- Comparing emissions from different biosolids management scenarios within a program
- Estimating the impacts on GHG emissions resulting from changes in a biosolids management program
- Understanding the factors with the greatest impact on increasing or reducing GHG emissions

Further updates were made by BEAM's creators, with version 1.1 the official version since 2011. In the interim, research has advanced and updating and validating the model further has been necessary. Between 2010 and 2021, several major upgrades to the calculator model were created by various users for clients such as the New York City Department of Environmental Protection (NYC DEP) and the San Francisco Public Utilities Commission as these organizations work toward municipal goals of becoming "carbon neutral" or better. There is also a new "module" or spreadsheet tab for a new unit process—pyrolysis with drying. Northwest Biosolids and NEBRA led a scientific review and update of

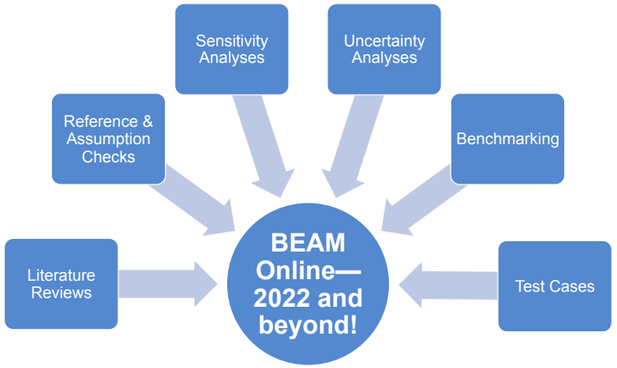


Figure 1. BEAM Evaluation Process

the model and created a website for sharing it. Although CCME was consulted and kept apprised of the current work, NEBRA and Northwest Biosolids assumed responsibility for BEAM*2022.

PLANS FOR KEEPING BEAM*2022 UPDATED

In 2021, NEBRA organized the BEAM*2022 science review team (SRT) consisting of five members—three academics and two PhD consultants. NEBRA created a protocol for annual reviews; the six elements are shown in Figure 1. The SRT conducts reference and assumption checks based on literature reviews. NEBRA performs sensitivity and uncertainty analyses, with SRT input and direction as needed. Benchmarking and test cases are done by BEAM users and will be collected on the new website, where users can share their BEAM spreadsheets and provide feedback for future annual reviews.

For BEAM*2022, the current updated model, the SRT focused on specific assumptions and factors that have a large impact on net GHG emissions from solids management, including, for example, the following:

- Rate of carbon sequestration when biosolids are land applied, varied based on soil type, climate, management practices, and other factors
- Nitrous oxide emissions from sewage sludge incineration and biosolids land application
- Fugitive methane from biosolids management, including in anaerobic digestion (AD) and combined heat and power systems (CHP)
- Default assumptions on percentage volatile solids reduction (VSR) in aerobic digestion and AD systems and similar important information in solids management processes

For this initial BEAM*2022, the SRT peer review process was accompanied by some additional stakeholder review involving an advisory group, which includes NEBRA's Carbon Trading Committee, the WEF GHG subcommittee, and other volunteer stakeholders. The advisory group will continue to help guide development of new modules and uses for BEAM*2022 that will be factored into each annual review.

Results of each annual SRT evaluation of BEAM*2022 will be incorporated by NEBRA into the spreadsheet calculator, with attention to the integrity of all links and references. Results will also be incorporated into the *User's Manual*, including, as needed, changes to any major assumptions, resulting limitations on model uses, and explanations concerning higher sensitivity, uncertainty, and ongoing research. The annual evaluation will likely help further prioritize and inform research and data collection related to understanding, measuring, and modeling GHG emissions associated with biosolids management.

USES OF BEAM*2022

Currently BEAM is a good tool for planning. The model can be used to estimate a program's GHG emissions, including establishing a baseline, comparing different biosolids management scenarios, and estimating impacts from changes in biosolids management. BEAM*2022 can help identify the most impactful actions a utility can take in managing their biosolids.

A long-term goal is to make BEAM acceptable for carbon accounting protocols. We need to demonstrate and validate our practices from a carbon impact standpoint if we want to maximize the benefits of these activities. Biosolids has not yet made it into any carbon accounting for carbon credits, although it does seem likely to fit, with some tweaks, in the climate action reserve's soil enrichment protocol. But the promise for model acceptance is there, and NEBRA's Carbon Trading Committee aims to move that along in collaboration with the rest of the BEAM*2022 advisory group.

HOW BEAM*2022 WORKS

BEAM*2022 calculates GHG emissions and allows the user to compare emissions in carbon dioxide equivalents (CO_2eq) across numerous different unit processes, including the following:

- Storage
- Conditioning/thickening
- Aerobic digestion
- Anaerobic digestion
- Dewatering
- Thermal drying
- Alkaline stabilization
- Composting (two types)
- Landfill disposal (typical, worst-case, aggressive, CA regulatory)
- Combustion
- Pyrolysis
- Land application (two types)
- Transportation

The calculations are based on data entered by the users that in turn are based on local measurements or factors. If no local data are available, the user can enter default emissions factors in the model from the latest peer-reviewed research. Color-coded cells indicate the type of data required, user inputs, default values, interim calculations that feed the default values, and emissions results. A separate tab contains references and assumptions. Emissions are calculated and reported as scope 1 (direct) and scopes 2 and 3 (indirect emissions from operations). BEAM*2022 can analyze numerous different scenarios. Figure 2 shows seven scenarios in which the IPCC standard 100-year timeline is used (but that can also be customized). Negative numbers are reductions in carbon dioxide equivalents—a good thing. Positive numbers show end uses that are increasing carbon emissions—what we want to avoid.

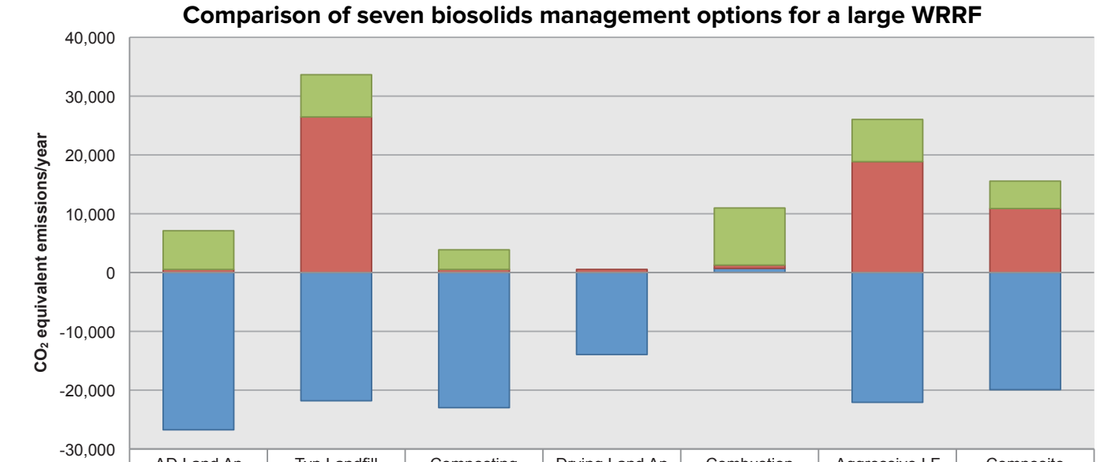
From reviewing research and using this GHG calculator, and seeing the results over the years, NEBRA can conclude that for typical situations landfilling biosolids has the highest emissions and negative impact on climate (based on default factors, typical emissions). BEAM*2022 results show that anaerobic digestion followed by land application or composting is much better in terms of carbon emissions: The decreased carbon resulting from use of these biosolids in lieu of commercial fertilizer and the estimated amount of carbon sequestered through biosolids land application far outweigh any carbon emissions from transportation and storage of the biosolids. Uncertainty remains, however, around nitrous oxide emissions from land application, and that is an active area of research.

BEAM*2022 helps emphasize critically important lessons regarding biosolids management and potential impacts on climate:

- Reducing energy and fossil fuel locally will reduce GHG emissions and save utilities money. Energy efficiency actions should be a priority for all WRRFs.
- Because wastewater and biosolids contain abundant energy—dried biosolids are similar in energy content to lower-grade coal—we can add to renewable energy generation. That is what modern WRRFs are all about.
- Most importantly, we manage organic—carbon-rich—materials that also contain nitrogen. That means there is significant potential for releasing fugitive methane and nitrous oxide. Any significant release of those two gases far outweighs carbon dioxide emissions from fossil fuel use. BEAM*2022 helps focus attention on these high-priority concerns.

MORE TO COME

BEAM*2022 is available online starting this spring at biosolidsghgs.org, a new, dedicated, non-profit website. This is intended not only to provide widespread public access to the updated spreadsheet calculator but also support resources and further share experience and knowledge around estimating, monitoring, and addressing GHG emissions from



	AD Land Ap	Typ Landfill	Composting	Drying Land Ap	Combustion	Aggressive LF	Composite
N_2O (CO_2eq)	6,573	7,171	3,334	0	9,702	7,171	4,658
CH_4 (CO_2eq)	533	26,469	533	533	558	18,863	10,890
CO_2	-26,742	-21,804	-22,981	-13,940	716	-22,070	-19,915

Figure 2. Example of BEAM*2022 output—comparing seven biosolids management options for a large WRRF

biosolids management. We hope it will be a central hub for advancing understanding of GHG emissions related to the management of wastewater solids. A new *User's Manual* is also in the works.

There will be many resources and much anticipated sharing of information by BEAM*2022 users with the goal of continually improving this GHG calculator for biosolids management programs. BEAM*2022 currently estimates GHG emissions from when the wastewater solids are wasted or removed from clarifiers or lagoons. Users have expressed interest in expanding the model upstream to include all WRRF processes, or at least ensuring that its outputs integrate well with large leading carbon accounting protocols, such as the corporate standard (ghgprotocol.org/corporate-standard).

NEBRA plans to review the model annually and update it as needed and as funding is available. Having a formal process to update data and assumptions helps ensure that this calculator is robust and reliable. This is important because voluntary—and in some cases regulatory—programs are increasingly requiring estimates and tracking of GHG emissions with goals of net reductions.

The future of biosolids management will involve carbon accounting. Research continues into the highest and best use of these "waste" materials. Using BEAM*2022 to estimate GHG emissions from various operations will help WRRFs understand the climate impacts from their operation. This could also help them communicate with customers and build support for low-impact, sustainable biosolids management programs. Using BEAM*2022 as a guide, WRRFs can make better long-term decisions, mitigate climate impacts, and become part of the circular economy.

ACKNOWLEDGMENTS

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REFERENCES

- Brown, S.; N. Beecher; and A. Carpenter. 2010. Calculator tool for determining greenhouse gas emissions for biosolids processing and end use. Env. Sci. & Tech. 44:24, 9509-9515. https://pubs.acs.org/doi/abs/10.1021/es101210k.
- CCME / Canadian Council of Ministers of the Environment. 2009. Biosolids Emissions Assessment Model: User Guide. PN 1430. ISBN 978-1-896997-86-5 PDF.

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