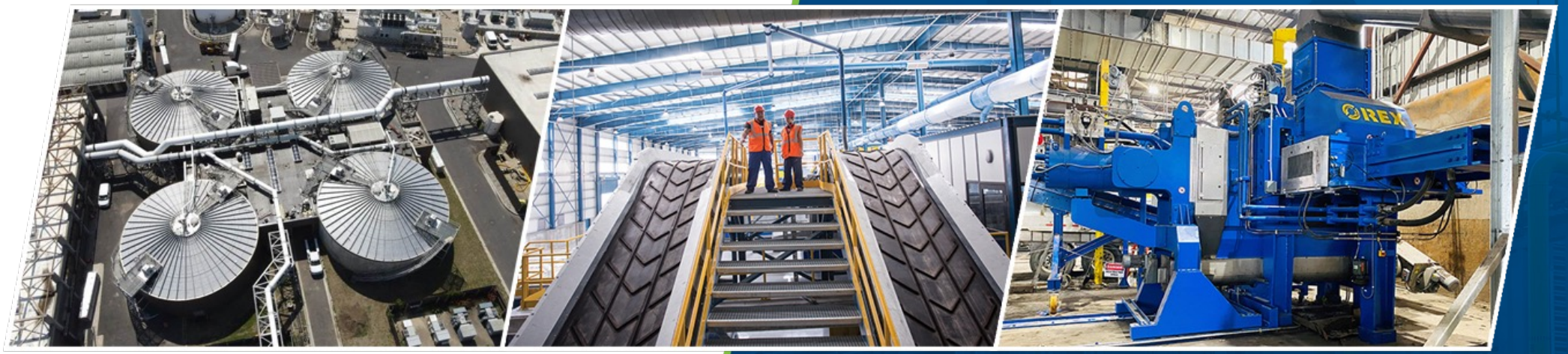
DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Rialto Advanced Pyrolysis Integrated Biorefinery



Andrew Dale, PE

Organic Waste Conversion

4/6/2023

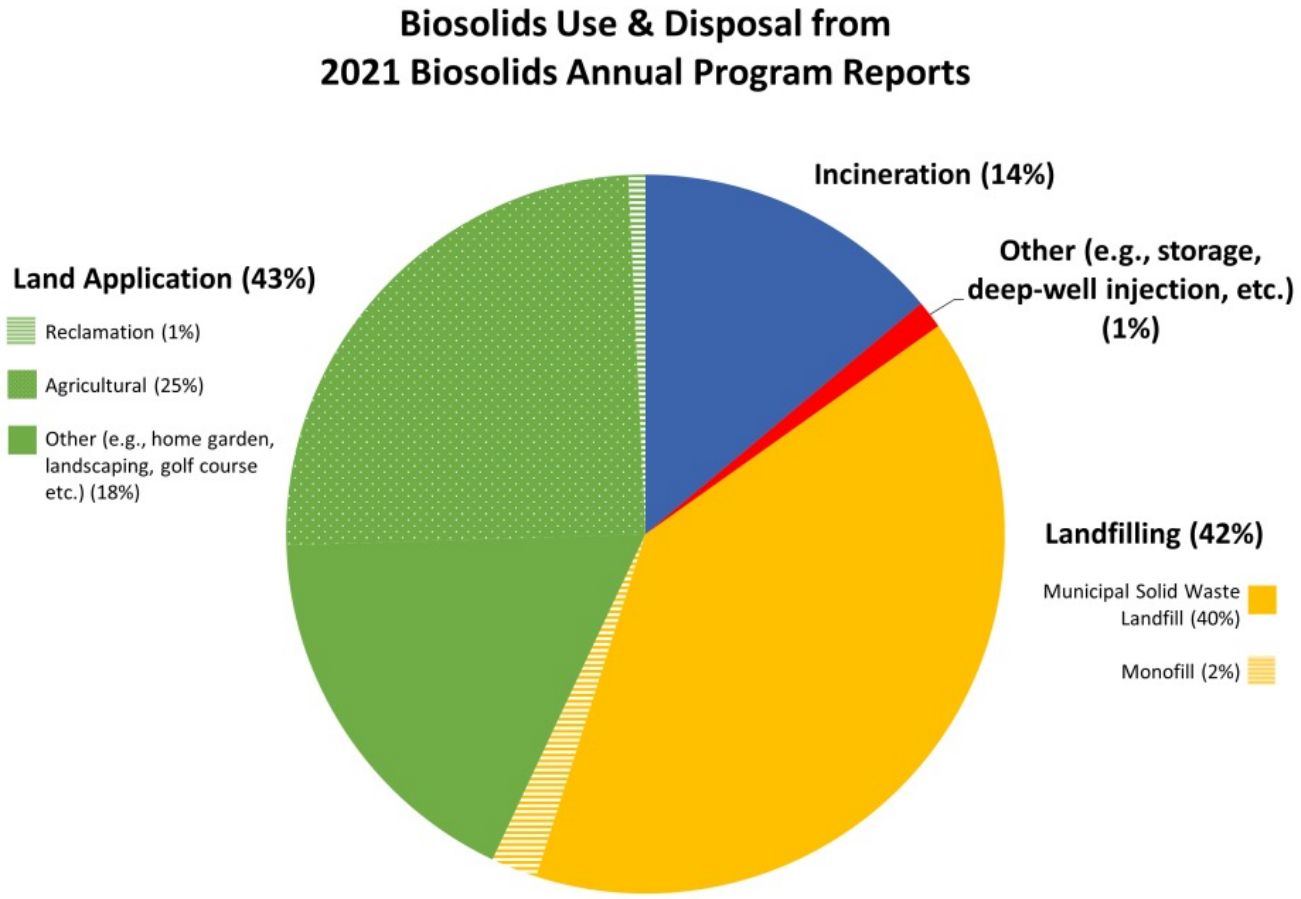
Anaergia

Fueling a Sustainable World

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Overview: Problem Statement

- Approximately 6 Million dry metric tons of biosolids are generated each year in the USA
- Current biosolids disposal methods are primarily land application and landfilling
- Municipalities are facing increased restriction on landfilling (ex. California's SB 1383) and will look to land application to fill the gap
- Current best practice for land application of biosolids is generation of Class A Exceptional Quality biosolids. Typically, through energy intensive thermal drying.
- However, these solids are still contaminated with PFAS "forever chemicals" and other contaminants of concern such as pharmaceutical, detergents, and hormones



From: https://www.epa.gov/biosolids/basic-information-about-biosolids#:~:text=Biosolids%20also%20may%20be%20disposed,other%20forms%20of%20surface%20disposal
.

Anaergia

Project Objectives

1. Construct a large scale (1000 ton per day) integrated mixed organics anaerobic digestion and pyrolysis solution which:

- Provides up to 1,000,000 MMBTU of RNG per year
- Is a repeatable model for California which diverts organics from landfills, reduces GHG emissions, and provides useful products from biosolids

2. Demonstrate a cost effective and net energy positive alternative to land application of biosolids through commercial production of Biochar

- Reduced levelized cost of biosolids disposal
- Sustainable alternative to destroy PFAS/PFOS and other contaminates of concern

Objective 2 requires pyrolysis which was analyzed and included with DOE Grant

Anaergia

Project History and Evolution

- Awarded 2017 to extract condensable oils from pyrolysis to enhance gas production in anaerobic digestion.
- In 2021, the EPA published new monitoring rules consistent with the EPA's PFAS strategic road map that highlighted the need for PFAS destruction in biosolids requiring Anaergia to re-evaluate the oil extraction from pyrolysis
- Laboratory testing identified PFAS chemicals in the condensable oils, which would concentrate PFAS in the digested solids
- Current objectives have shifted from extracting the condensable oil to increase gas production to PFAS destruction

Project objectives evolved due to potential PFAS regulations.

Anaergia

Project Description

- Rialto Bioenergy Facility receives 700 tons per day of food waste for anaerobic digestion to produce RNG and 300 tons per day of municipal wastewater biosolids which are dried to Class A EQ standards and land applied.
- Pyrolysis unit is in construction to pyrolyze 75 tons per day of Class A EQ dried biosolids into biochar
- Biosolids are further processed into a uniform, marketable fertilizer product by blending with other conventional fertilizers and granulating

Anaergia

Project Overview: Current Objectives

Current Objectives:

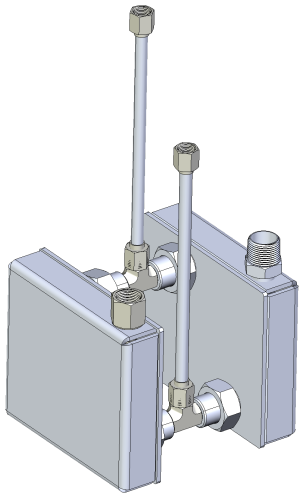
- Volatilize PFAS and other contaminants of concern from the biosolids being applied to land
- Destroy PFAS compounds in the produced gas from pyrolysis through thermal oxidation
- Recover heat from pyrolysis to reduce natural gas demand for drying biosolids
- Demonstrate the net carbon removal of land applied biosolids biochar to generate carbon dioxide removal certificates (CORCs)
- Demonstrate the effectiveness of biosolids biochar as a replacement for conventional fertilizing materials

Approach

- Internal lab testing to determine the fate of the PFAS chemicals in pyrolysis
- Mass and Energy balance development
- Pilot testing with academic partnerships to verify the fate of PFAS chemicals
- Detailed engineering and process design
- Staged facility construction
- Evaluation of agronomic impacts on crop production
- Development of fertilizer grade product from biosolids biochar

Progress and Outcomes

- Built in house lab pyrolysis reactor to develop preliminary mass and energy balance and test for contaminant destruction
- Confirmed lab data through pilot testing with academic and private sector
- Determined PFAS remain in oil; cannot feed to anaerobic digester



Lab Pyrolyzer

Pilot Plant for
PhD studies

Sample Collection

Anaergia

Progress and Outcomes

	Biosolid [ng/g]	350°C Biochar	650°C Biochar	350°C Bioextract [ng/g]	350°C Oil [ng/g]	650°C Bioextract [ng/g]	650°C Oil [ng/g]
4:2 Fluorotelomer sulfonic acid	ND	ND	ND	ND	ND	ND	ND
6:2 Fluorotelomer sulfonic acid	ND	1,2	ND	ND	ND	ND	ND
8:2 Fluorotelomer sulfonic acid	ND	ND	ND	ND	ND	ND	ND
NEtFOSAA	1,2	ND	ND	ND	2,0	ND	0.26
NMeFOSAA	2,2	ND	ND	ND	3,2	ND	0.23
Perfluorobutanesulfonic acid	0,94	ND	ND	ND	ND	0.26	1.1 I
Perfluorobutanoic acid	1	ND	ND	7,2	16	20	18
Perfluorodecanesulfonic acid	1,5	0,2	ND	ND	ND	ND	ND
Perfluorodecanoic acid	1,7	ND	ND	ND	0,90	ND	0.20
Perfluorododecanoic acid	0,82	ND	ND	ND	0,42	ND	ND
Perfluoroheptanesulfonic acid	0,39	ND	ND	ND	ND	ND	ND
Perfluoroheptanoic acid	0,25	ND	ND	0.12	2,9	ND	0,81
Perfluorohexanesulfonic acid	ND	0,41	ND	ND	ND	ND	ND
Perfluorohexanoic acid	3,5	ND	ND	1,0	15	0,42	4.3
Perfluorononanesulfonic acid	ND	ND	ND	ND	ND	ND	ND
Perfluorononanoic acid	0,39	ND	ND	ND	1,1	ND	0.27
Perfluorooctanesulfonamide	ND	ND	ND	ND	2,0	ND	0.24
Perfluorooctanesulfonic acid	11	5,6	ND	ND	ND	ND	ND
Perfluorooctanoic acid	1,2	ND	ND	ND	4,4	ND	1,2
Perfluoropentanesulfonic acid	ND	ND	ND	ND	ND	ND	ND
Perfluoropentanoic acid	2	ND	ND	3,4	3,9	0,34	2,9
Perfluorotetradecanoic acid	0,42	ND	ND	ND	ND	ND	ND
Perfluorotridecanoic acid	ND	ND	ND	ND	ND	ND	ND
Perfluoroundecanoic acid	0,6	ND	ND	ND	0.49	ND	ND

- High temperatures of greater than 350 C needed to volatilize PFAS from biosolids
- Pyrolysis alone does not destroy PFAS and they are present in pyrolysis products
- Further processing (Thermal Oxidation) will be required for all volatilized products
- Recycle to digester no longer aligns with PFAS destruction goals

Anaergia

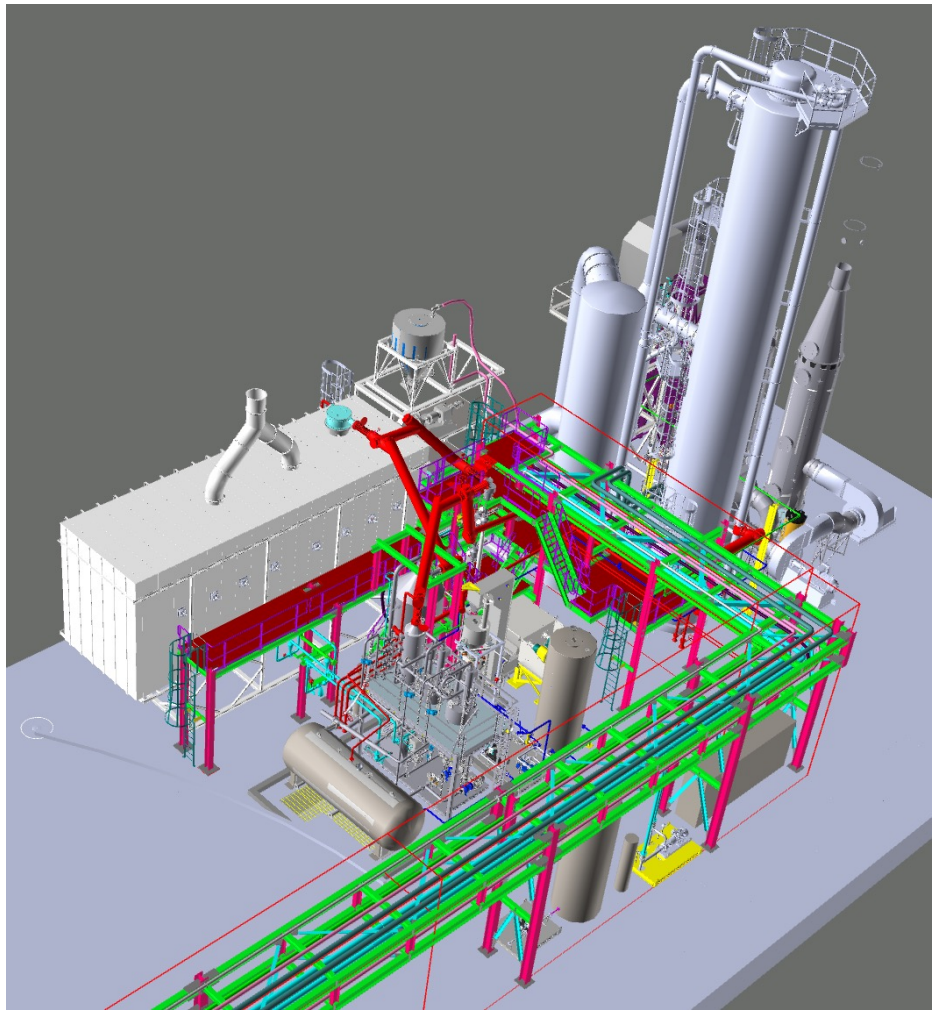
Progress and Outcomes

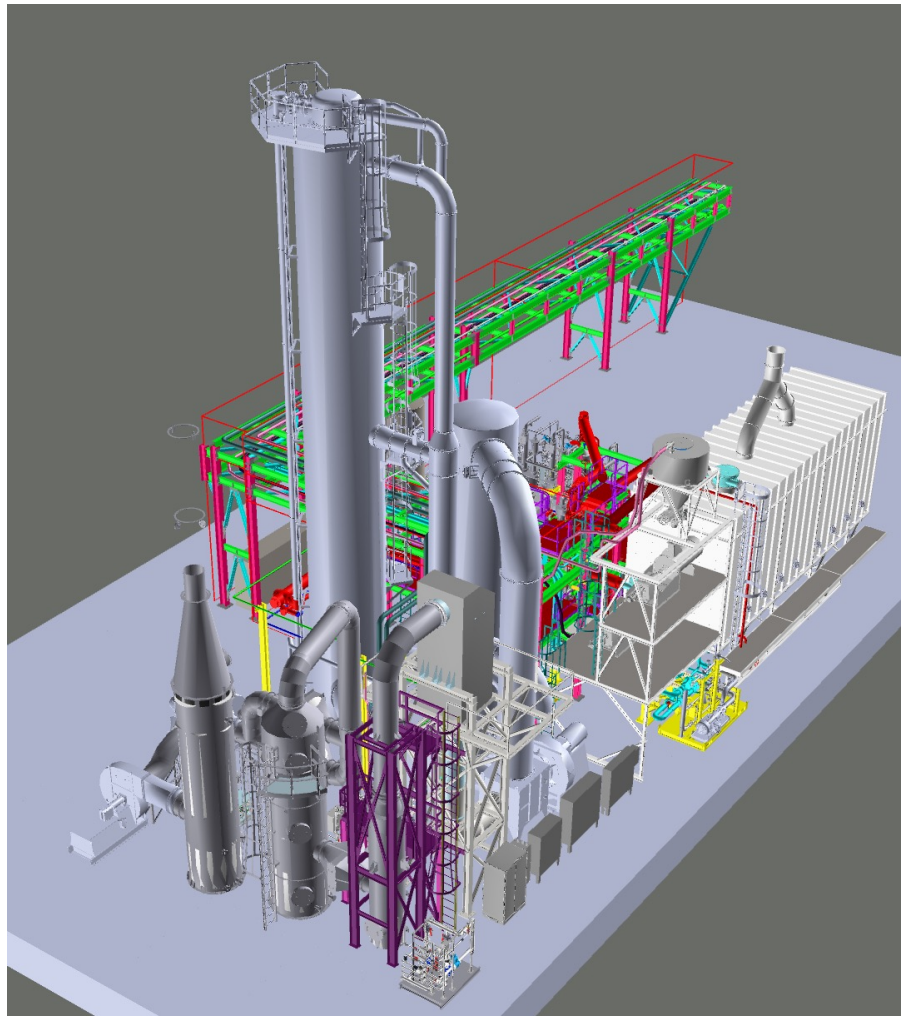
Analyte	Detection Limit (ng/g)	Biosolids (ng/g)	650 C Biochar (ng/g)
2-hydroxy-ibuprofen	4.0	48.6	ND[1]
Bisphenol A	6.0	1760	ND
Carbamazepine	0.02	24.0	ND
Estrogen	22.5	31.4	ND
Furosemide	4.0	9.4	ND
Gemfibrozil	0.8	35.0	ND
Glipizide	0.8	ND	ND
Glyburide	0.8	ND	ND
Hydrochlorothiazide	8.5	11.6	ND
Ibuprofen	4.0	121	ND
Naproxen	2.0	25.5	ND
Sulfamethoxazole	0.03	0.3	ND
Triclocarban	0.4	207	ND
Triclosan	6.0	2310	ND
Trimethoprim	0.02	2.6	ND
Warfarin	0.4	ND	ND

- High temperatures of greater than 350 C needed to volatilize other contaminants of concern from biosolids
- 650°C was found to be sufficient to eliminate all PFAS and contaminants of concern from the resultant biochar product

Anaergia

Progress and Outcomes: Detailed Engineering Design





- Worked with industrial partners for equipment supply and detailed design of 75 dry ton per day high temperature pyrolysis plant

Anaergia

Progress and Outcomes: Phased Construction

300 WTPD biosolids dryers currently installed and operating

Pyrolysis Installation as of Dec 2022

Anaergia

Progress and Outcomes: Land Application

Current Scenario

- RBF producing dried biosolids
- Land Application in AZ and CA
- Cost to Rialto Bioenergy Facility: $65/ton

Future

- RBF will produce pyrolyzed biosolids starting Q4 2023

- Pyrolyzed biosolids has value as soil amendment
  - Marketable nutrient (P), carbon, and humic acid content
  - Marketable benefits – water retention

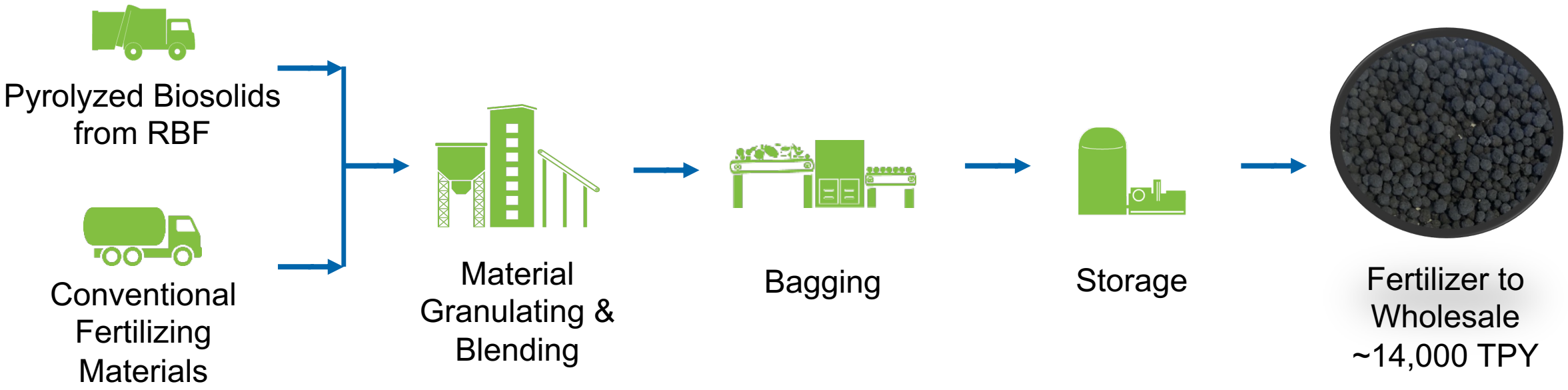
- High dust levels of pyrolyzed biosolids pose unacceptable environmental risk to many outlets
  - CA-based land application options will not accept dusty material
  - Example: Aries restricted from land application in NJ

Dust generated from application of pyrolyzed biosolids

Anaergia

Progress and Outcomes:

Create marketable product by blending pyrolyzed biosolids with added conventional nutrients to (1) reduce dust levels and (2) improve product familiarity for consumers

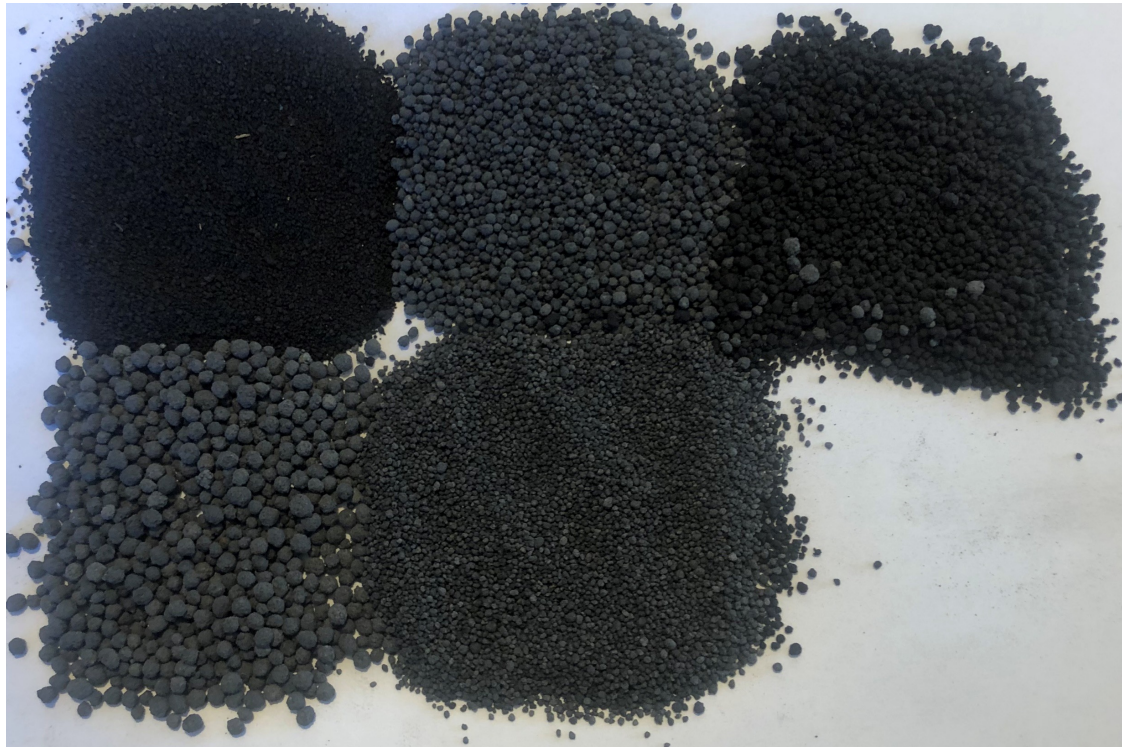


Pyrolyzed Biosolids will be blended with conventional fertilizers to create a balanced, marketable fertilizer product ready for end users

Anaergia

Progress and Outcomes

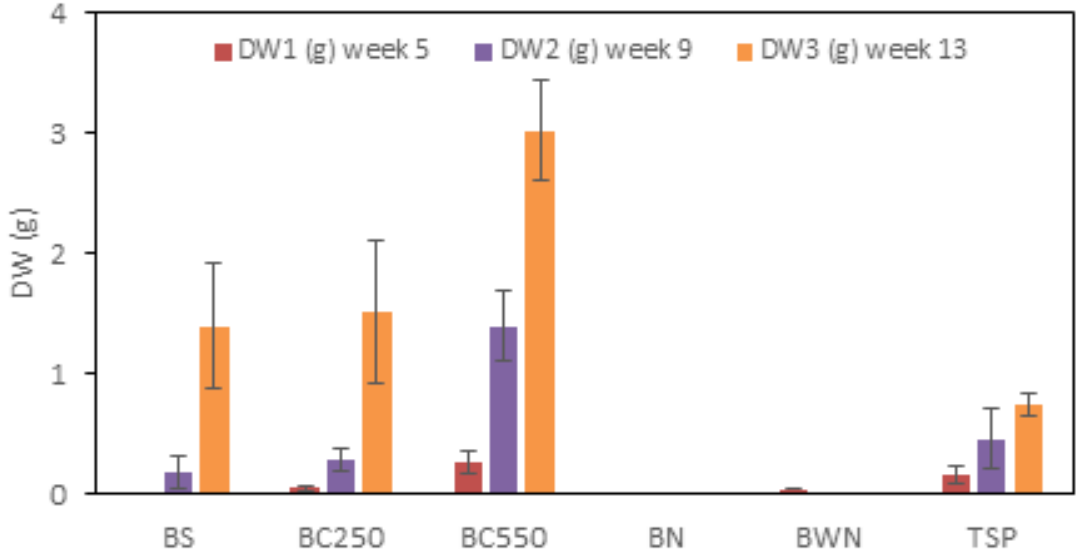
- Tested equipment to produce a consistent, uniform, granular fertilizer product by blending
- Completed design of a fertilizer blending and bagging facility to process

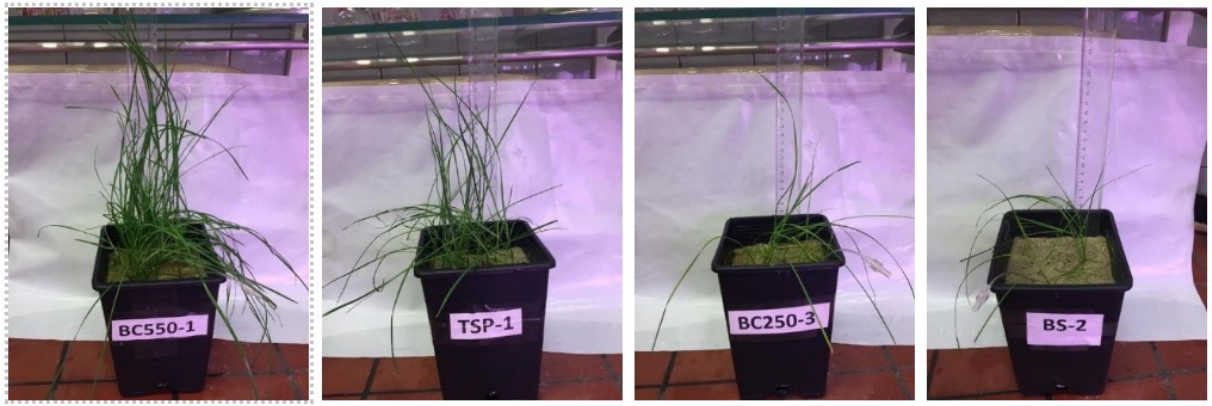


Granulation trial formulations of blended biochar fertilizers for various agricultural applications

Anaergia

Biochar Research Trials: Perrenial Ryegrass (PRG) Greenhouse Studies





The tested phosphorous nutrient solutions were as follows:

- Biosolids derived from domestic and commercial sewage sludge (BN)
- Biosolids biochar produced from pyrolysis at 250°C (BC 250)
- Biosolids biochar produced from pyrolysis at 550°C (BC 550)
- A conventional phosphate fertilizer product, triple super phosphate (TSP)

BC550 outperformed all other nutrient solutions, as evidenced by a greater dry weight and root development of PRG collected throughout the study and visibly faster growth of the PRG.

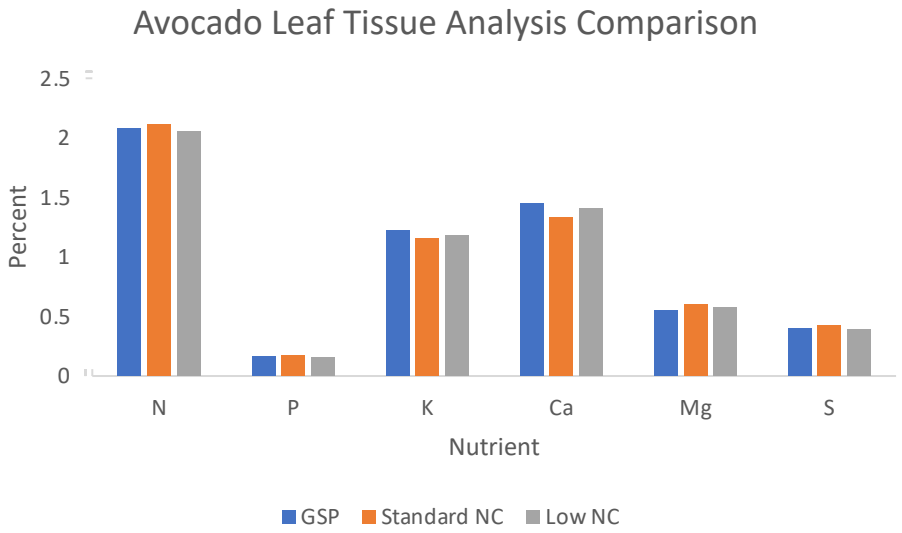
Anaergia

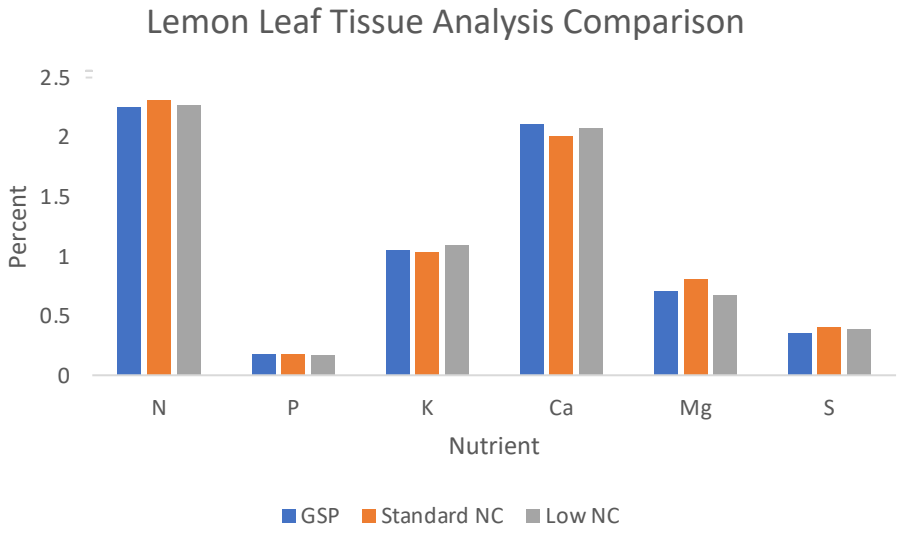
Biochar Research Trials: Avocado and Lemon Field Studies

Anaergia is conducting trials comparing our biosolids biochar (8-8-8) blended biochar fertilizer to conventional Triple 15 (15-15-15) fertilizer for use in avocado and lemon production.

Trees were fertilized using Triple 15 (15-15-15) at the grower standard application rate and compared to an equivalent application rate (Standard NC) and a 50% lower application rate (Low NC).

Initial leaf tissue test results suggest that nutrient uptake in plants fertilized with standard and lower levels of nutrients are in line with that of growers standard practice. This suggests that NitroChar is an effective replacement for conventional fertilizer and may potentially be used at a lower rate and maintain the same effectiveness.





Anaergia

Biochar Research Trials: Alfalfa and Oat Hay Field Studies

Anaergia is conducting field trials using biosolids biochar as a replacement for conventional fertilizers in alfalfa and oat hay.

Initial germination data suggests no negative impact on seed germination and stand establishment. Trials were planted in December 2022 and January 2023 and will be harvested in May of 2023. Yield data, tissue analysis and soil analysis will be conducted to determine impacts on crop and soil health.

Anaergia

Impact

- EPA PFAS in biosolids regulations expected winter 2024
- This project demonstrates a technically and commercially viable pathway to remove PFAS from biosolids prior to land application
- Rialto Bioenergy Facility is permitted for 300 wtpd biosolids processing in South Coast Air Quality Management District
- Biosolids offtake agreements with LA and Orange County due to pyrolysis and pfas destruction
- Potential upgrading of biosolids biochar into a marketable consumer ready product
- Bio-oil found to contain PFAS, so it will not be routed to the anaerobic digester
- Municipal wastewater utilities have been greatly interested in these results and the success of the project with many adding pyrolysis or other thermochemical conversion processes into their master planning

Quad Chart Overview

Timeline

Project start date January 15, 2017

Project end date 2024

	FY22 Costed	Total Award
DOE Funding	*(10/01/2021 – 9/30/2022)* *$0*	*(negotiated total federal share)* *$3M*
Project Cost Share *		

Project Goal

Demonstrate a cost effective and net energy positive alternative to land application of biosolids through commercial production of Biochar

End of Project Milestone

Additional Deliverables to be added include:

-Testing Results from further pyrolysis testing

-Updated Final P&ID for Pyrolysis integration at Rialto Bioenergy Facility

-Updated site plans for integration of full-scale demonstration

Funding Mechanism

DE-FOA-0001232: FUNDING OPPORTUNITY ANNOUNCEMENT (FOA) NUMBER DE-FOA-0001232: PROJECT DEVELOPMENT FOR PILOT AND DEMONSTRATION SCALE MANUFACTURING OF BIOFUELS, BIOPRODUCTS AND BIOPOWER (PD2B3)

Project Partners – None

Summary

- PFAS and other contaminant of concern removal from biosolids has been proven
- Bio-oil contains PFAS and thus cannot be sent to AD
- Blended biochar fertilizers developed and ready for commercialization
- Construction nearing completion and preparing for commissioning
- Future Work:
  - Confirm LCA for carbon dioxide removal certificates with real life operational data
  - Determine fate of PFAS and other CEC through thermal oxidation and flue gas treatment train
  - Hypothesized PFAS fate via thermal oxidation: PFAS converted HF in high temperature thermal oxidation followed by HF neutralization to Sodium Fluoride in caustic scrubber in flue gas treatment train.

Anaergia