DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

An Advanced Pretreatment/Anaerobic Digestion (APAD) Technology for Increased conversion of Sewage Sludge to Bio-natural gas in small-scale wastewater plants of less than five dry ton sewage sludge per day

3/10/2021

Organic waste

Principal Investigator: Birgitte K. Ahring
Washington State University

Information on Timeline of the APAD Project

- The project was submitted for the BETO 2019 call FOA-0002029 under the area AOI 9: Rethinking Anaerobic Digestion July 2019
- The selection of the proposal was October 2019

BP 1 moved slowly due to Covid-19

- The PI worked with the BETO Project Managers (Mark Philbrick and Ian Rowe) on revision of the SOPO until end of January 2020
- The Review meeting was in April 2020 with positive outcome
- The final contract was received by WSU in the end of August 2020 with a DOE start date for BP2 ofJuly 1, 2020
- The sub-awards were finalized and the project started work on October 1, 2020

BP2 has now been under way for 4 months

- A no-cost extension of the BP2 end date will be applied for in the Fall 2021

This Project is 4 month into execution

Project Overview

<u>Problem</u>: Energy production from sewage sludge especially at small-scale using Anaerobic Digestion (AD) typically do not produce significant value with the current available AD technology due to low Carbon Conversion Efficiency (CCE) (generally less than 50%). We propose a novel concept, which will overcome this problem and produce significant more energy product in a more valuable form as Bio-natural gas.

<u>Project goals:</u>

1. *Significantly increase the CCE of conventional AD (from 45 to 70% end of BP2 and to 75% end of BP3)*
2. *Upgrade biogas (60% CH_4/40% CO_2) to RNG. Converting 80% of CO2 with H2 to more CH4 end of BP2 and 95% of CO2 end of BP3.*

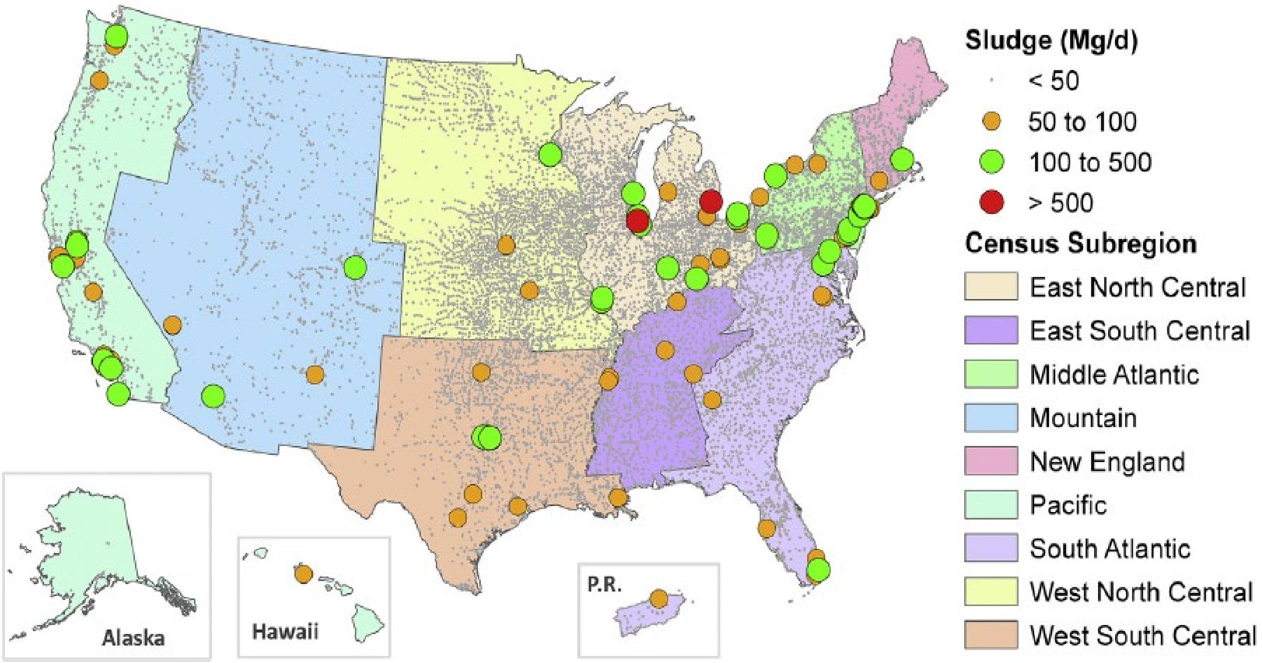
<u>Importance:</u>

The project could significantly reduce cost and energy consumption of treating and disposal of sewage sludge along with greenhouse gas emission. Production of RNG expand the use of sewage sludge as a feedstock for producing transportation biofuels from organic waste.

<u>Risk:</u>

The risk of the project is that the defined milestones will not be met. However, the baseline data forming the background for the project showed a CCE improvement of 30% well above the current state of art for AD of sewage sludge.

Project Overview



In the USA there are far more Wastewater Treatment Plants (WWTPs) with small wastewater and Sludge volumes (ca. 30% of all sludge is produced here and ready for exploitation)

Production of RNG at small WWTP could stimulate local economy in rural areas while reducing disposal cost for sewage sludge

1. Management

Traditional Management Phases- we are now in the Execute Phase

Initiate

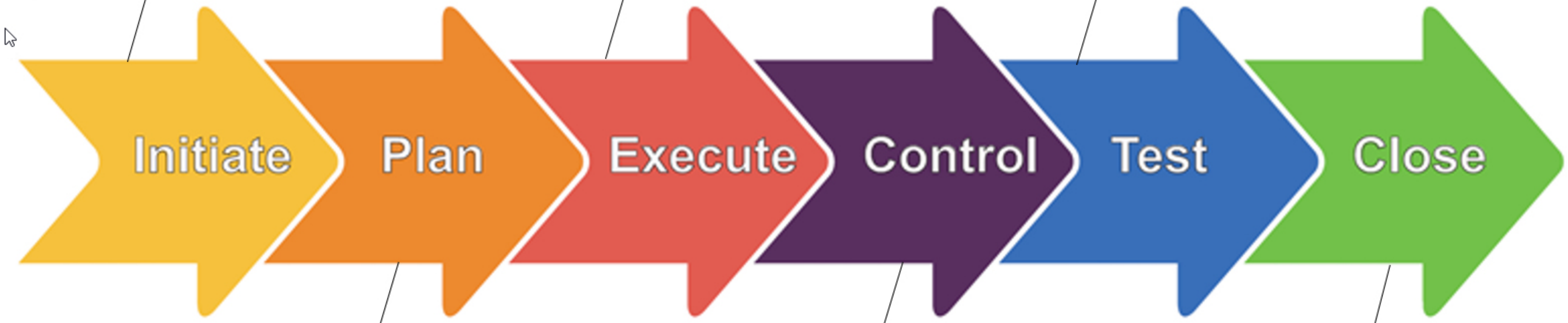
Define the business case
Complete the project charter
Complete the statement of work
Document project constraints
Identify project team members

Execute

Manage the project schedule Versus
Implement statement of work
Provide design documents
Manage and assess risk
Monitor quality and cost
Communicate established frequency

Test Plan

A document describing the scope, approach, resources, and schedule of intended testing activities.
Develop user acceptance testing
Documentation and signoff
Develop test scripts



Plan

Identify resources
Develop a detailed project plan
Develop functional design document
Establish project timeframe
Assess project risks and summarize in risk assessment

Control

Manage project scope
Manage schedule, milestones and tasks
Project status meetings (on going)
Manage quality control
Manage project costs
Manage project quality
Manage project communications
Manage project risk management
Manage contract and procurement

Close - Signoff

Summarize charter deliverables and actual accomplishments
Complete project closeout report

1. Management

APAD Partners

Washington State University (WSU)

B. Ahring (PI),M. Garcia-Perez

Role: Lead Task 4 (AD), Task 5 (CO_2 conversion) ,Task 6 (Pilot testing)

CleanVantage LLC

R. Garrison (lead), P. Teller

Role: Lead Task 2 (Collection/dewatering of sludge), Task 3 (Pretreatment),Task 6 (Pilot testing)

PNNL

R. Zheng (lead), T. Seiple

Role: Lead Task 7 (TEA, LCA and Bio-solids disposal model)

Jacobs Engineering

W. Breshears (lead), Jarrod Burden

Role: Operates WW WTTP, Providing sewage sludge, Input on Operations, Upscaling

City of Walla Walla

F. Nicholson (lead)

Role: Provides data for WW and engaged in the upscaling of the APAD into WW WWTP

Richland WWTP is further connected to the project

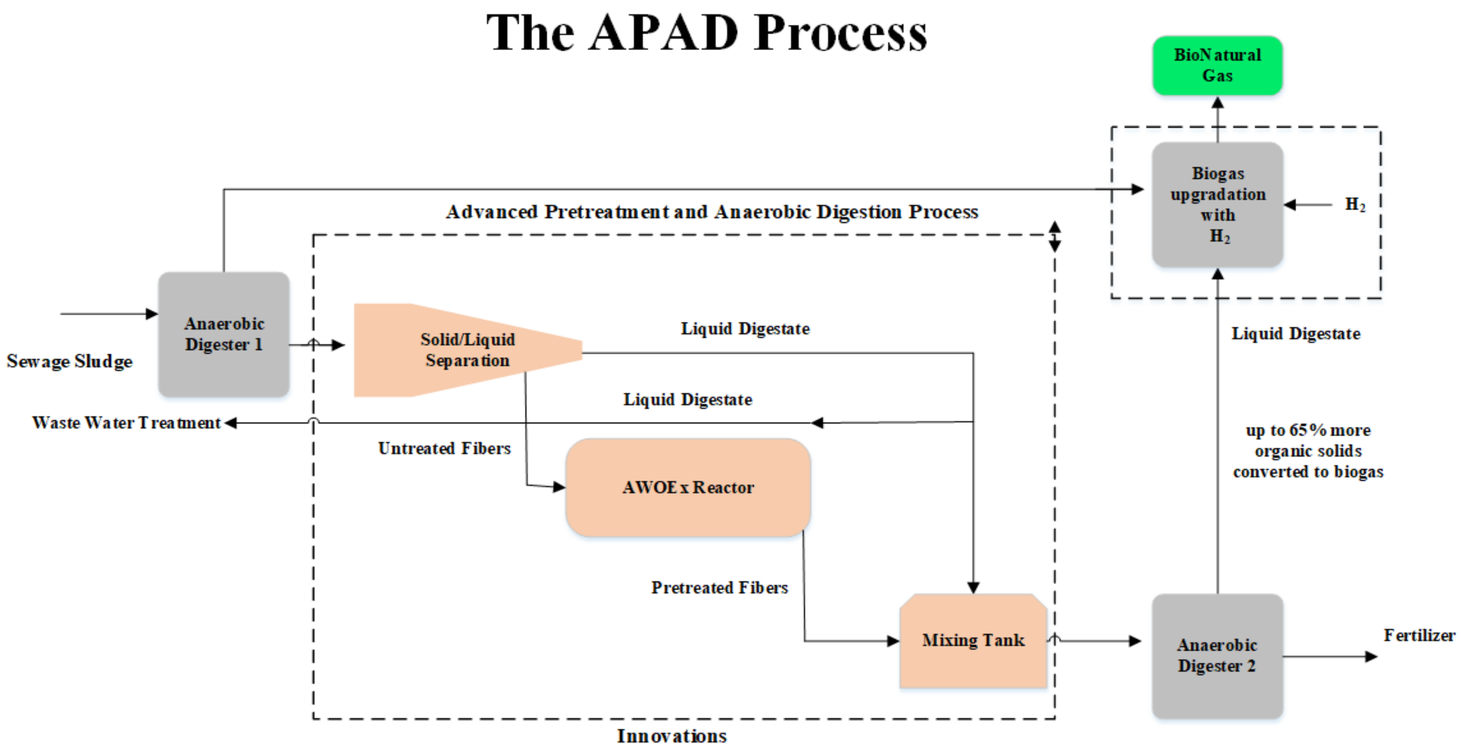
1. Management

All partners are members of the management team.
Items such as those shown are addressed at our monthly meetings.

1. Management
Project Risks and Proposed Abatements

Project Risk	Project Abatement
Concentration of AD digested sewage sludge to 25% or more is found to be difficult	We will solve this by using other flocculants and concentration methods
AWOex pretreatment do not produce the CCE's as anticipated	We will use other oxidants than oxygen to enhance the effect
The CO_2 conversion with H_2 to CH_4 do not produce the expected reductions in CO_2	We will operated the methanogenic fermentation in two steps after each other to increase the overall efficiency

2. Approach

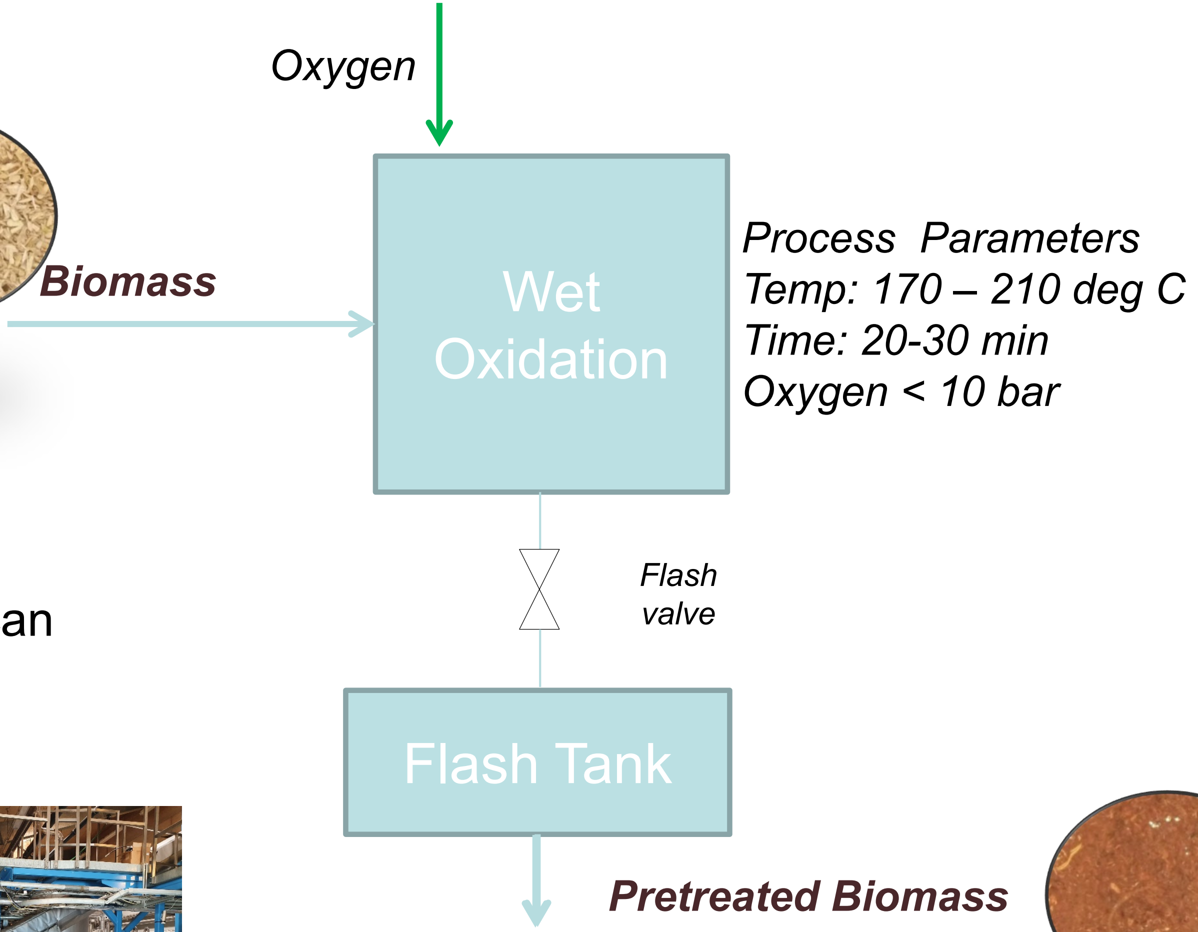


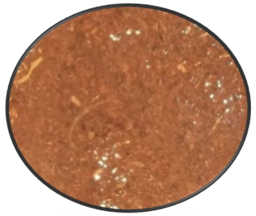
The boxes are the innovate steps of the APAD Process

2. Approach

Advanced Wet Explosion Pretreatment

AWOex was originally developed for pretreating lignocellulosic biomass materials for producing biofuels





AWOex has been tested with 26 different types of biomass and shown a superior ability to produce a pretreated homogenized material at 30% DW, which can produce high sugar yield (150 g/L) with low cellulolytic enzyme doses

AWOex scaled up with manure/straw:
AD-Booster (3 ton/hour),
Ribe Biogas Denmark (30% increased roduction CH4 production).

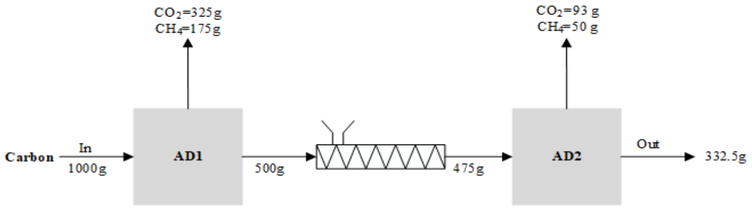
Advantages of pretreating remaining solids after AD1

- Reduces the volume of biomass to be pretreated, which lower cost of pretreatment
- Performing the pretreatment only on the recalcitrant portion of the sludge
- The pretreatment is more effective after a biological conversion process
- The AD2 reactor can operate at low retention time and high solids loading due to changed rheology of the pretreated sludge
- Economically sound and efficient (uses max. 15% of extra energy produced)

Evolving Development of Technology Configuration to Enable Success

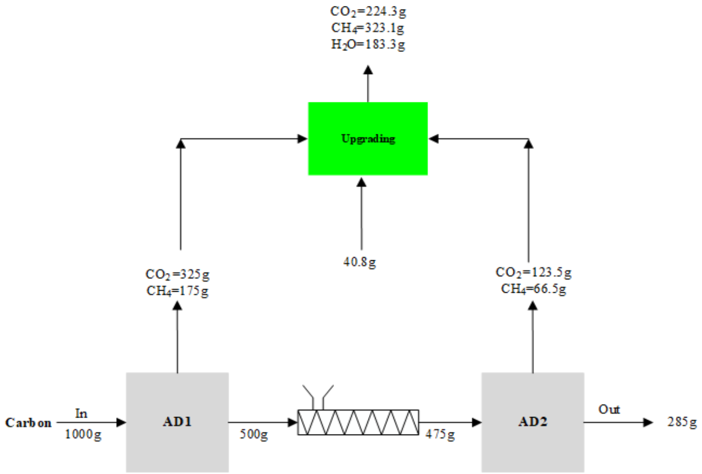
Base Case

Base Case (28.6% CH_4 Increase compared to conventional AD)



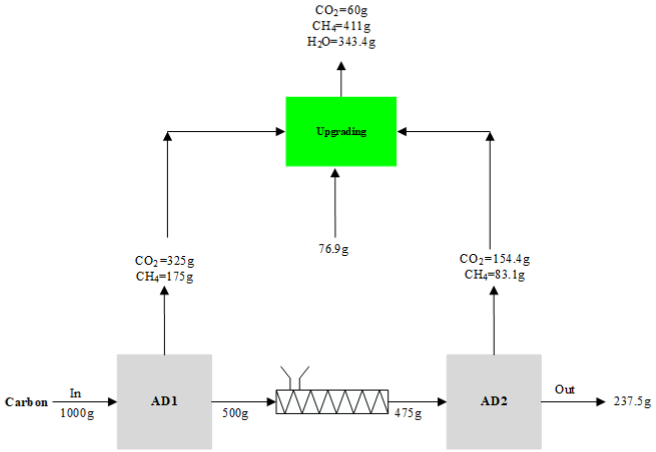
Intermediate Case (85% CH_4 Increase compared to conventional AD)

Intermediate Case



End Case (135% CH_4 Increase compared to conventional AD)

End Case



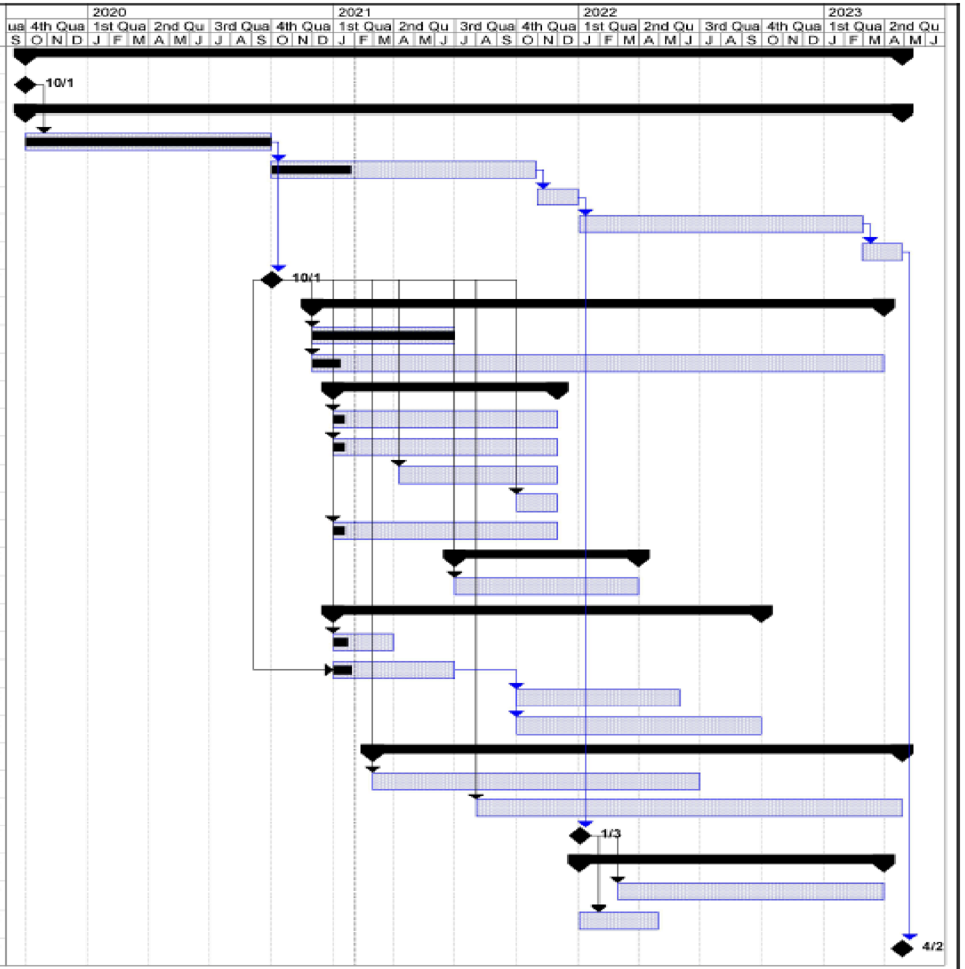
2. Approach

Tasks	Milestone Type	Milestone Description	Responsibility	Anticipated months
Task 1	Milestone	Verification by DOE team; intermediate and final visit	DOE Team/ project Partners	Months 1-5, 6-21, 22-36
Go/No-Go#1		Demonstrating the baseline goal: 30% higher Carbon conversion efficiency and methane yield compared to Conventional AD.	Verification Team	April 1, 2020
Go/No-Go#2		Demonstration of the intermediate goals: 40% higher Carbon conversion efficiency and 80% CO2 conversion from biogas giving 85% higher CH4 yield compared to conventional AD.	Verification Team	December 31, 2021
End Goal Verification		Demonstration of the end goal: 50% higher Carbon conversion efficiency and 95% CO2 conversion from biogas giving 135% higher CH_4 yield compared to conventional AD	Verification Team	April 31, 2023

Overall Milestones for the APAD project

Gantt Chart over APAD project

ID	Task Name	Duration	Start	Finish
1	**Active Tracking Schedule**	**934 days**	**Tue 10/1/19**	**Fri 4/28/23**
2	Start BP-1	0 days	Tue 10/1/19	Tue 10/1/19
3	**Task 1 -- DOE Verification Team**	**934 days**	**Tue 10/1/19**	**Fri 4/28/23**
4	Task 1.1 - BP-2 Verification	262 days	Tue 10/1/19	Wed 9/30/20
5	BP-2 Project Review by DOE	282 days	Thu 10/1/20	Fri 10/29/21
6	Task 1.2 - BP-3 Verification	45 days	Mon 11/1/21	Fri 12/31/21
7	BP-3 Project Review by DOE	302 days	Mon 1/3/22	Tue 2/28/23
8	Task 1.3 - Completion Verification	44 days	Tue 2/28/23	Fri 4/28/23
9	Start BP-2	0 days	Thu 10/1/20	Thu 10/1/20
10	**Task 2 -- >25% dewatered sludge**	**609 days**	**Tue 12/1/20**	**Fri 3/31/23**
11	Task 2.1 Select Dewatering Method	152 days	Tue 12/1/20	Wed 6/30/21
12	Task 2.2 Dewater Digested Sludge	609 days	Tue 12/1/20	Fri 3/31/23
13	**Task 3 -- pretreatment parameters**	**238 days**	**Fri 1/1/21**	**Tue 11/30/21**
14	Task 3.1 Optimize AWOEx	238 days	Fri 1/1/21	Tue 11/30/21
15	Task 3.2 Test AWOEx	238 days	Fri 1/1/21	Tue 11/30/21
16	Task 3.3 AWOEx gas yield	168 days	Fri 4/9/21	Tue 11/30/21
17	Task 3.4 AWOEx Data Analysis	43 days	Fri 10/1/21	Tue 11/30/21
18	Task 3.5 AWOEx Samples Lab/Pilot	238 days	Fri 1/1/21	Tue 11/30/21
19	**Task 4 -- carbon conversion parameters**	**196 days**	**Thu 7/1/21**	**Thu 3/31/22**
20	Task 4.1 Optimize AD of samples	196 days	Thu 7/1/21	Thu 3/31/22
21	**Task 5 -- CO2 conversion**	**456 days**	**Fri 1/1/21**	**Fri 9/30/22**
22	Task 5.1 Optimize H2/biogas	64 days	Fri 1/1/21	Wed 3/31/21
23	Task 5.2 Construct Reactor	129 days	Fri 1/1/21	Wed 6/30/21
24	Task 5.3 Optimize gas and liquid rates	173 days	Fri 10/1/21	Tue 5/31/22
25	Task 5.4 Optimize CO2 reduction	261 days	Fri 10/1/21	Fri 9/30/22
26	**Task 7 -- TEA/LC analysis**	**565 days**	**Mon 3/1/21**	**Fri 4/28/23**
27	Task 7.1 Model biosolids disposal	349 days	Mon 3/1/21	Thu 6/30/22
28	Task 7.2 TEA/LCA	455 days	Mon 8/2/21	Fri 4/28/23
29	Start BP-3	0 days	Mon 1/3/22	Mon 1/3/22
30	**Task 6**	**325 days**	**Mon 1/3/22**	**Fri 3/31/23**
31	Task 6.1 Pilot Testing	284 days	Tue 3/1/22	Fri 3/31/23
32	Task 6.2 Mass Energy Balance	85 days	Mon 1/3/22	Fri 4/29/22
33	Verify Completion	0 days	Fri 4/28/23	Fri 4/28/23



Project: 2020 1520
Date: Mon 2/1/21

Task, Split, Progress, Milestone, Summary, Project Summary, External Tasks, External Milestone, Deadline

Page 1

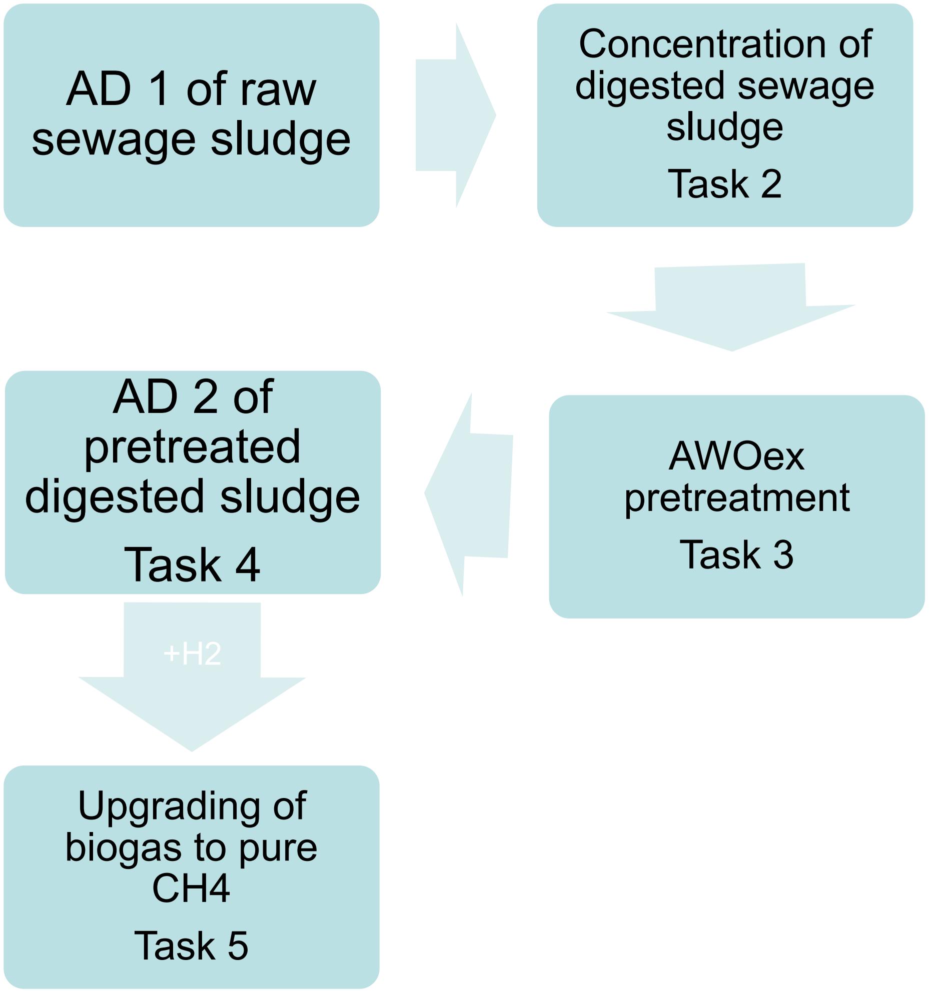
Process Work Flow

BP 2:

- Examining and optimizing each process stepwise separately in the laboratory starting with concentration of sludge after AD 1. Development of a Mass and Energy balance for the optimized process
- Using TEA to guide the way and for selection of the best overall operational conditions for each step.

BP 3:

- Testing and optimization of the integrated process operated at the optimal operational conditions in small pilot scale corresponding to 11 Gallons AD 1 sludge/day
- Verification of the final Mass and Energy Balance
- Input from pilot will be used for the final TEA, LCA and Sludge disposal model



3. Impact

- The project will allow for systematic testing and optimization of the APAD process and for an understanding of the potential of this process compared to conventional AD
- The project will further allow for a better understanding of biological biogas upgrading to bio-natural gas using a realistic set-up with real materials
- Our stake-holders in the project are small wastewater treatment plants (WWTP in Walla Walla and Richland) and our focus is on designing realistic processes, which are economically viable in small scale (max. 5 ton/day sewage sludge).
- However, the results will further be interesting for larger WWTP plants situated in larger cities where the RNG can be integrated with the natural gas grid.

Dissemination of Insights

- We will publish data from the project on an ongoing basis. The PI has over 500 papers with review, an H-index of 87 and ca. 30,000 citations.
- The data we produced in the fourth quarter of 2020 (our first period) along with the preliminary results from BP1 is now being collected for publication. We expect to submit this paper in the second quarter of 2021.
- We are always on the forefront of patent opportunities- the PI has 12 international patent and new inventions will be covered along the way.
- Our plan is to present results from the project at conferences in the end of 2021/2022.
- We are planning on hosting a Workshop for a broader group of stakeholders when the integrated pilot plant is up in operation (BP 3).

"*We have great expectations for the APAD project and the opportunity of producing more biogas from our sewage sludge" Frank Nicholson, City of Walla Walla*

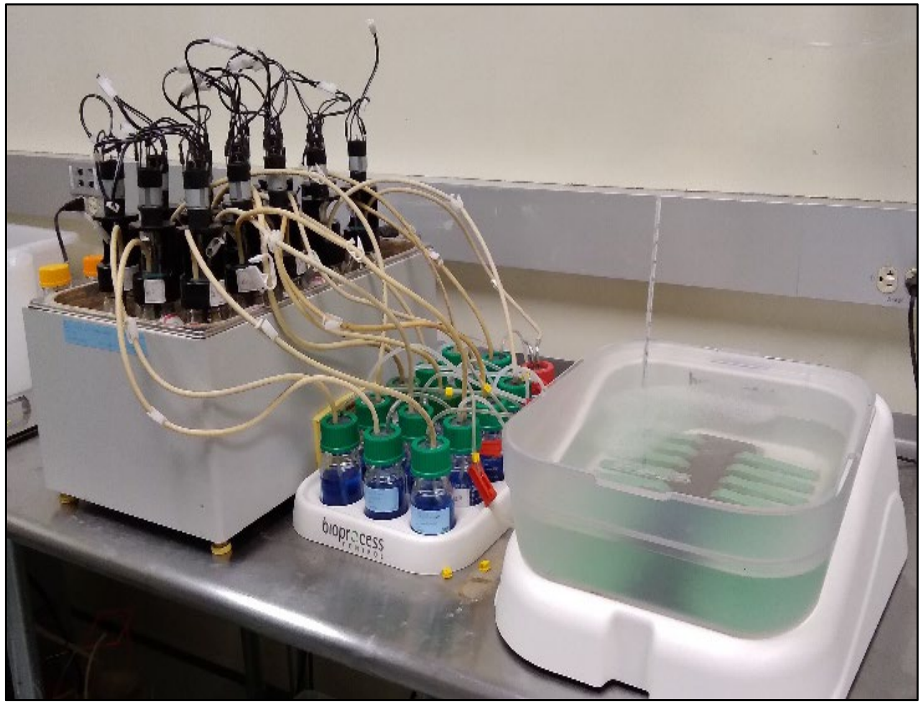
Results from Task 2: Collection and concentration of sewage sludge

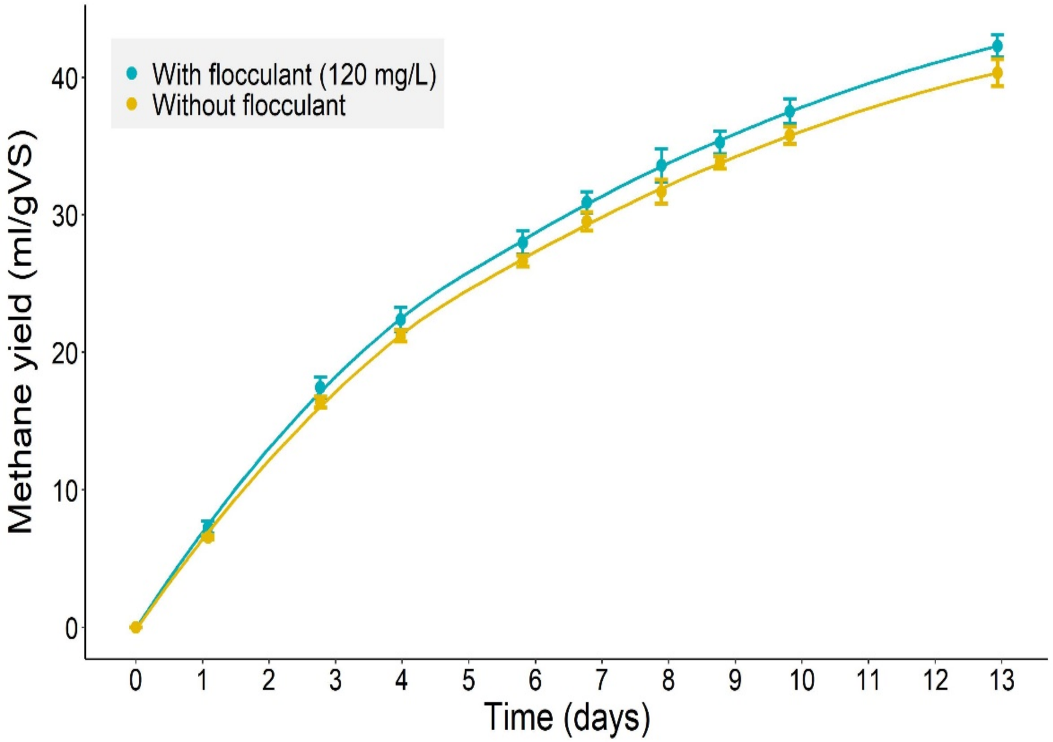
- We have collected sewage sludge from Walla Walla WWTP and tested the dewatering ability with different methods. Decanter centrifugation was found to be superior for concentrating digested sludge- but need another flocculent than used at Walla Walla WWTP today for reaching the goal of 25% dry matter or more
- Sludge flocculated at Walla Walla WWTP using T-Floc B-135, an aluminum chlorohydrate, showed problems with decanter centrifugation due to clumping of the material.
- We have established a collaboration with Thatcher Company (major flocculants producer) and will test 4 other cost-effective flocculants in the first quarter of 2021 (based on polyacrylamide).

Overall: *Task 2 has established a significant link between flocculation technique, performance, and cost.*

4. Progress and Outcome

Results from testing of flocculent T-Floc B-135 on methane yield from digested sewage sludge show no inhibition at normal concentrations of the flocculent.



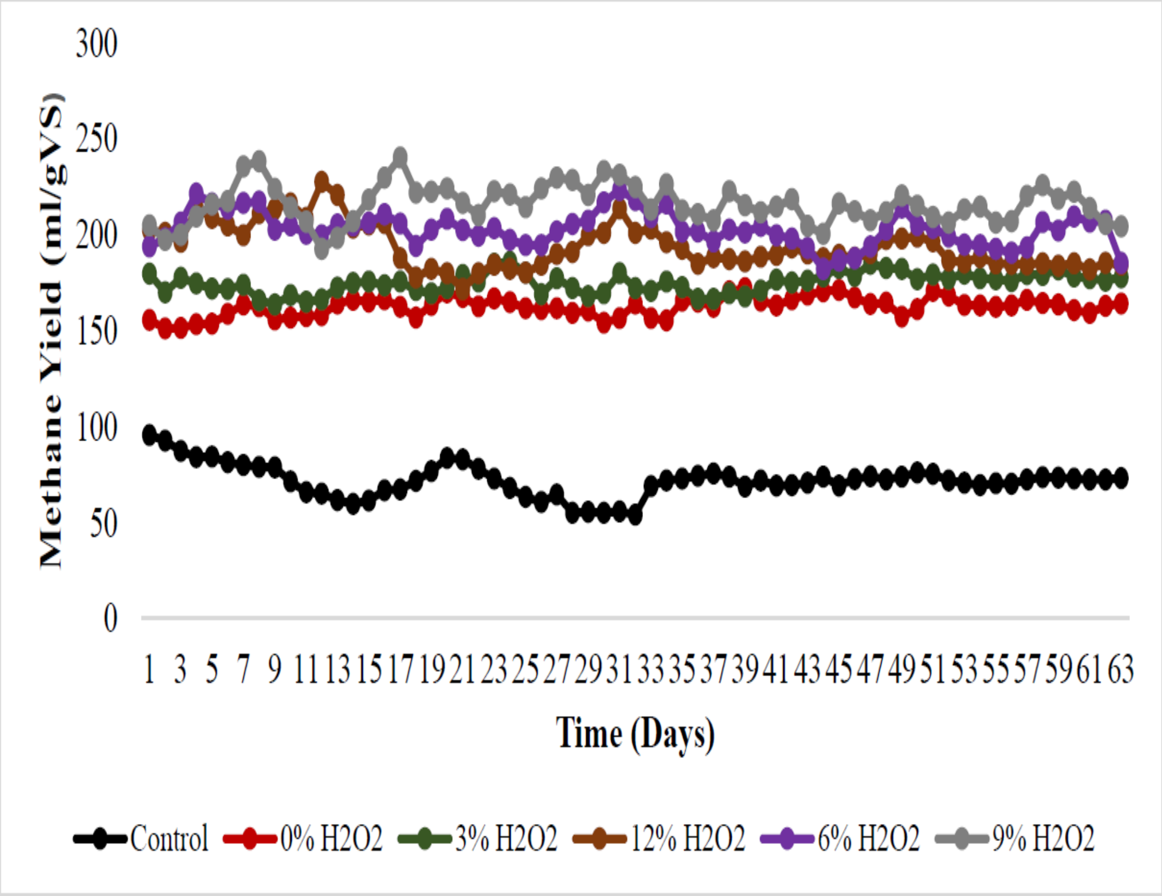


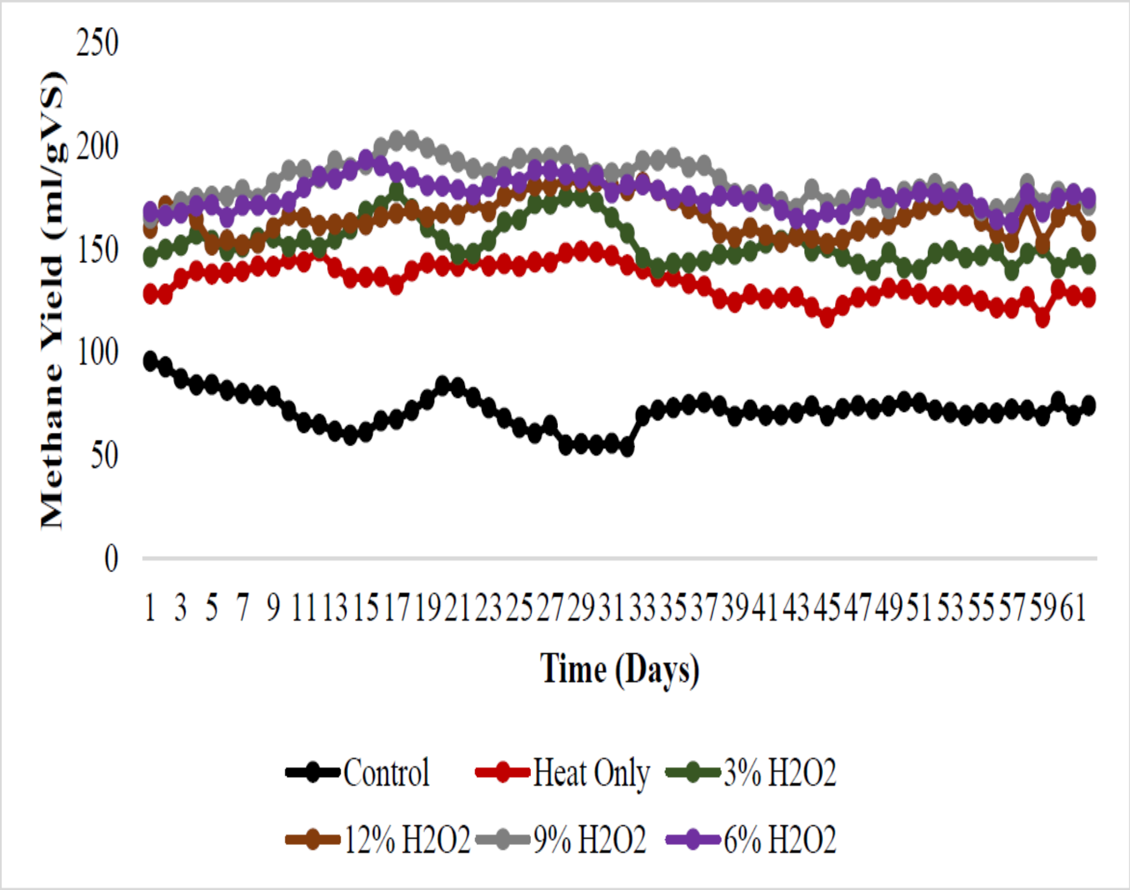
4. Progress and Outcome

TASK 3:

Pretreatment of dewatered digested sewage sludge by Wet oxidation. Methane Yield from pretreated (180°C-left) and (210°C-right) AD1 sewage sludge at different oxygen levels (H2O2 addition) compared to control without pretreatment

Overall: ***Pretreatment at 180°C gives higher methane yields and the highest yield is with 9% H2O2***



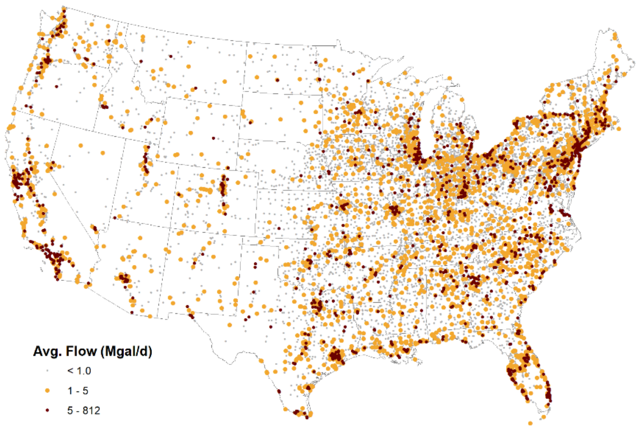


4. Progress and Outcome

Task 7.1 – Model biosolids disposal practices and costs

- **Distribution of 1-5 Mgal/d (small) WWTPs**

Flow Range *(Mgal/d)*	Total *WWTP*	% WWTP	Total Flow (Bgal/d)	% Flow
<1	11392	76	2.3	7
1 -5	2511	17	5.9	17
>5	1105	7	26.2	76
Total	15008	1	34.4	1



- **Transportation cost modeling approach selected** – Adoption of approach by Marufuzzaman et al. (2015) and Berwick and Farooq (2013) to estimate the scaled delivery costs of post-APAD biosolids for representative wastewater treatment plants ranging in size from 1 to 5 Mgal/d of average dry weather influent flow.

For each scale (1—5 Mgal/d) | @ 20-35% solids
@ 85-100 $/h | @ 0—50 km | Costs by endpoint & distance

Mass (kg/y wet) → Volume (m^3/y) →  → Land Apply & Landfill ADC →
- $/Mg dry
- $/y

4. Progress and Outcome

Task 7.1 – Model biosolids disposal practices and costs

- **Hauling Costs –** Truck transport costs to include fixed and variable costs. Fixed costs are independent of travel distance and are incurred regardless of truck utilization. Variable costs depend on the total distance travelled per trip.
- **National Average Tipping Fees** – Tipping fees are a major cost component of the landfill disposal pathway. A recent national survey conducted by the Environment Research & Education Foundation (EREF, 2019) indicated a national average landfill tipping fee of $55.36 per wet ton.
- **Spreading Costs** – Pending completion of cost models calibrated using publicly available reporting data, input from regional biosolids managers and wastewater experts, and recent municipal budget and planning info.

4. Progress and Outcome
Task 7.2 – LCA/TEA

- **Process model development –** Literature survey conducted on published anaerobic digestor process models. Model selection for APAD will be finalized with input from project teams. AWOEx and biogas upgrade reactor model development will start next quarter.
- **Process economics** – Costs associated with thermophilic anaerobic digestors, biogas cleanup unit, and APAD derived additional wastewater streams are best sourced using wastewater treatment industry specific simulation and costing tools, rather than Aspen. Subcontract with a US wastewater treatment consulting firm is being explored to produce independent and realistic cost estimates.

Summary

- **Overview.** The APAD project uses AWOex to enhance the CCE of digested sewage sludge and a biological upgrading process for converting CO2 from biogas into pure methane.
- **Management.** The project is managed through a monthly project meeting included all partners where issues related to the Task, Resources and Risk etc. are discussed and resolved.
- **Approach.** The major process step will first be optimized separately and then integrated in the laboratory/pilot to provide input for the Mass and Energy Balance, TEA, LCA and Sludge Disposal Model.
- **Impact.** The project could significantly increase energy production of sewage sludge as well as reduce cost of disposal of sewage sludge. Production of RNG expands the use of sewage sludge as a feedstock for producing transportation biofuels from organic waste
- **Progress and Outcomes (4 month)**
- Have established a significant link between flocculation technique, performance, and cost of concentrating digested sewage sludge to 25% DW or more
- Developed new partnership with the flocculent producer Thatcher Company
- Pretreatment at 180^{o}C with/without Oxygen (6-9%) was found superior over 210^{o}C and the methane yield increased 2.6 times over control (no pretreatment) and 1.4 time over samples pretreated with heat (180^{o}C), but no oxygen
- Work on the sewage sludge disposal model has established hauling and tipping fees while spreading costs are in progress

Quad Chart Overview (Competitive Project)

Timeline

- Project start date: Our date is October 1, 2019
- Project end date: Our date is April 31, 2023

	FY20 Costed	Total Award
DOE Funding	(10/01/2019 – 4/30/2023)	*$2,428,281*
Project Cost Share	$607,070	$3,035,351

- Partner 1: Washington State University
- Partner 2: Clean-Vantage, LLC
- Partner 3: PNNL
- Partner 4: Jacobs Engineering
- Partner 5: City of Walla Walla

Project Goal

The main goal of this project is to develop and demonstrate a concept for significant increased Carbon Conversion Efficiency of sewage sludge compared to conventional Anaerobic Digestion. A second goal is to develop a biological process for cost-effective conversion of CO2 from biogas into pure methane with hydrogen addition.

End of Project Milestone

End case: 50% improved Carbon conversion efficiency with conversion of 95% of the CO2 in the biogas with hydrogen to results in a total increase of 135% CH4 compared to conventional AD. A comprehensive techno-economic analysis (TEA) and a Life-cycle assessment will be available along with a Biosolids disposal model .

Funding Mechanism

BETO 2019 April call FOA-0002029 under the area AOI 9: Rethinking Anaerobic Digestion. The requirements for the call was a process showing 50% increase in CCE or a 50% decrease in disposal cost.

*.

Appendix

WSU Pilot facility used for APAD

The Team In-front of one AD1 at Walla Walla WWTP