Utilization of Biosolids: Soil Fertilization & Energy Production

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Outline

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  - Rationale
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  - Approaches
- Literature review
- Materials and methods
- Results
  - Land application
  - Gasification
- Take home messages
- Acknowledgements

Introduction

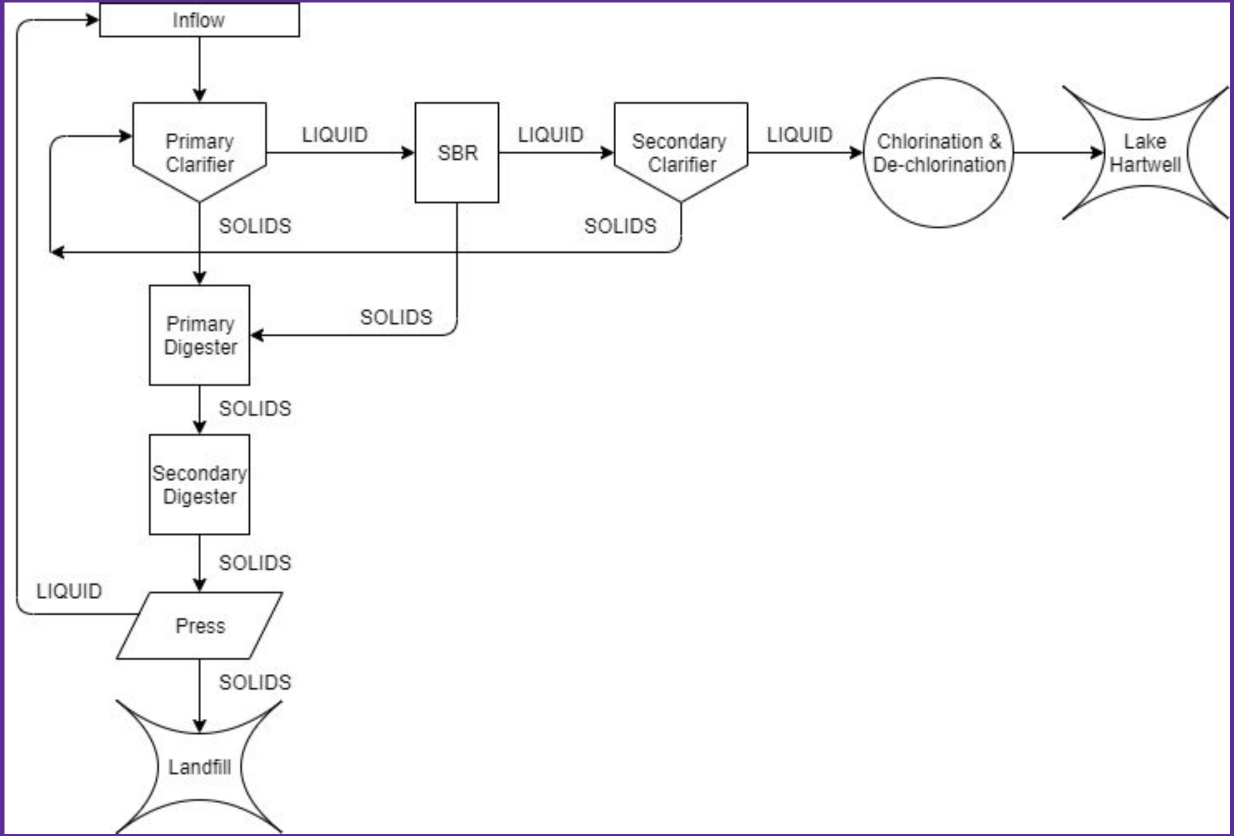
Sewage Treatment Plants

- Human waste will always be produced
- Typical treatment processes

Treatment Step	Description
Primary treatment	solid separation by sedimentation and filtration
Secondary treatment	reduction of BOD by microorganisms
Tertiary treatment	removal of excess pollutants and nutrients

- Main products
  - Treated water
  - Biosolids
- Definitions
  - **Sewage sludge:** pre-treated solid waste
  - **Biosolids:** post-treated solid waste

Clemson University WWTP



Clemson University WWTP

- Biosolids
  - Exit secondary digester as 2-3% solid
  - Exit dewatering press at 18% solid
  - Sent to the Anderson County landfill (Subtitle-D, Class III)
- Historical masses produced

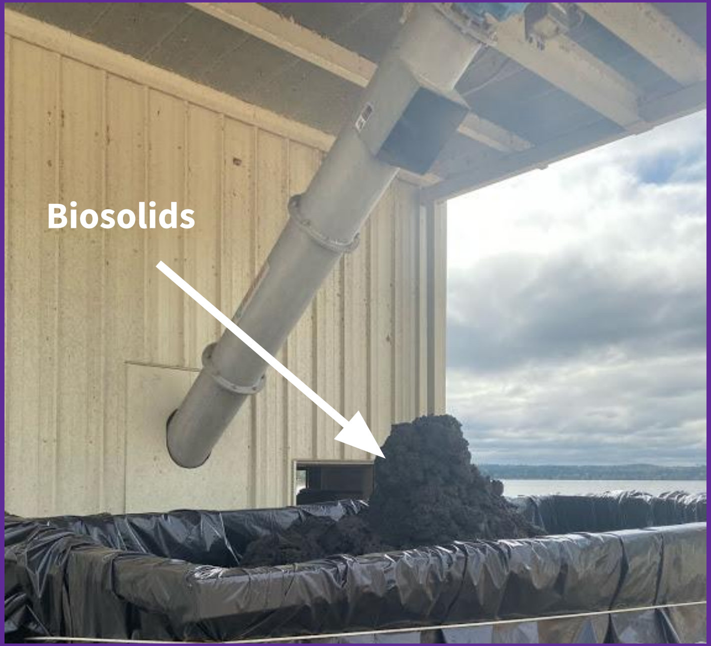
Year	Produced Biosolids (tons)
2017	745.08
2018	871.49
2019 (as of 11/11/19)	786.91

- Future increases
  - Enrollment
  - New College of Business building

Aerial View of Clemson University Wastewater Treatment Plant

Biosolids

- Beneficial components
  - Organic compounds (C)
  - Micronutrients (B, Cu, Fe, Mn, Mo, Zn)
  - Macronutrients
- Negative components
  - Praestol Polymer
  - Pathogens (e.g., *E. coli*, *C. jejuni*, *V. cholerae*)
  - Heavy metals (As, Cd, Cu, Pb, Hg, Mo, Ni, Se, Zn)
  - Pesticides (e.g., organophosphates, organochlorines)
  - Endocrine disruptors (e.g., androgens, estrogens)
  - Polyfluoroalkyl Substances (PFAS)
  - Microplastics
  - Toxic organic compounds
  - Excess nutrients (C, N, P)
  - Detergents
  - Salts



- Potential Uses
  - Land application
  - Gasification
  - Incineration
  - Composting
  - Landfill

Biosolid Nutrient Composition

Nutrient	Concentration (mg/kg-dry)	Minimum Detectable Limit (mg/kg-dry)
Phosphorus	46400	363
Nitrogen, TKN	42900	1870
Nitrogen, total	43200	50
Nitrite	BRL	8.55
Nitrate	262	2.14
Ammonia	2610	112

Metal	Concentration (mg/L)	Minimum Detectable Limit (mg/L)
Mercury	BRL	0.00048
Arsenic	BRL	0.0705
Barium	0.0802	0.0155
Cadmium	BRL	0.008
Chromium	BRL	0.0125
Lead	BRL	0.014
Selenium	BRL	0.044
Silver	BRL	0.0065
Potassium	2380	39.7

Polymer

- Praestol™ K 274 FLX FLOCCULANT
  - Created by Solenis
  - Harmful to aquatic life with long lasting effects
  - Cannot be inhaled
  - Should not be allowed to enter drains, water courses or soil
  - EC50 (Daphnia (water flea)): 0.17 mg/L

GHS Sym

Harmful / Irritant

Health Hazard

Rationale

The CU WWTP currently produces more than 800 tons of dewatered biosolids per year. Unfortunately, these nutrient-dense materials are currently being sent to the Anderson County landfill. Alternative uses of the biosolids produced from the CU WWTP must be developed to make Clemson University carbon neutral, economically profitable, and socially sustainable.

Objective

The objective of this project is to design a viable pathway to utilize the biosolids coming from the Clemson University wastewater treatment facility.

Approaches

Task 1. To review information regarding the CU WWTP, land application, gasification, and the related regulations

Task 2. To determine fecal coliform concentrations by sampling the biosolids produced at the CU WWTP

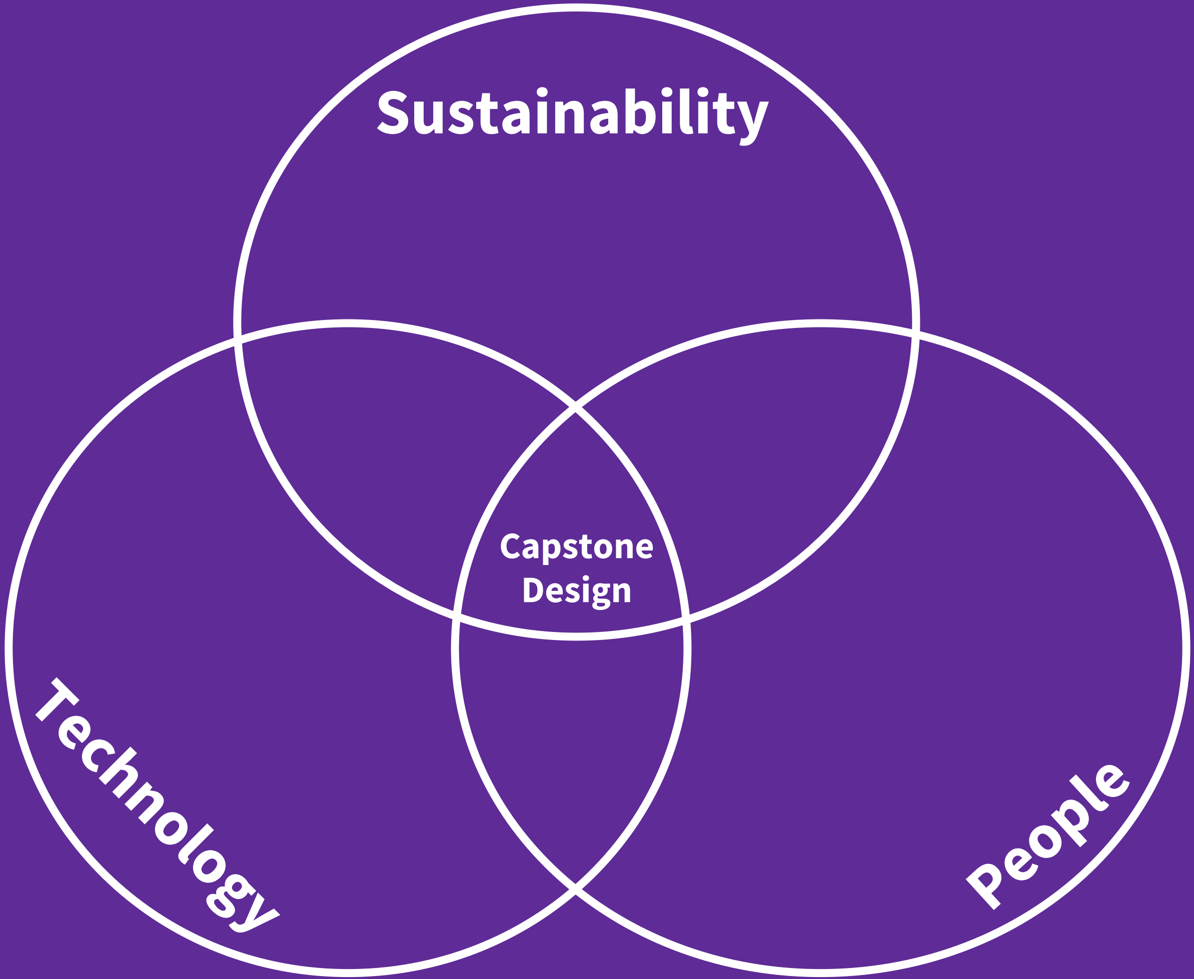
Task 3. To identify a process to reduce pathogen concentration

Task 4. To investigate alternatives to hazardous flocculation methods

Task 5. To select locations and estimate volumes for the land application of biosolids

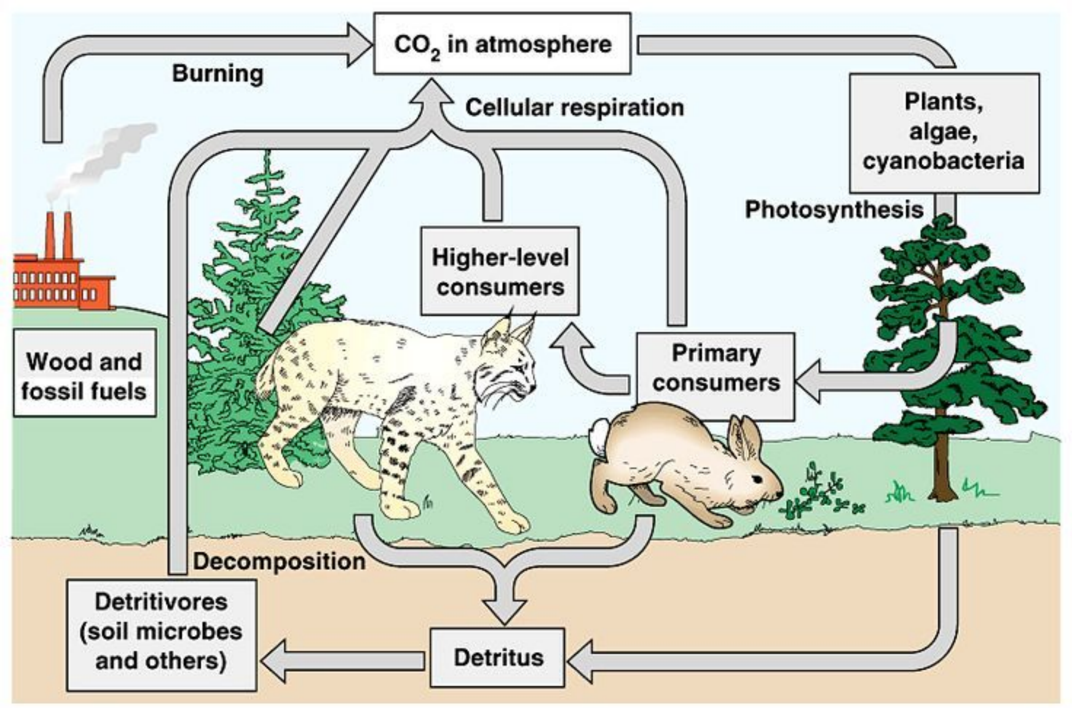
Task 6. To design and model a gasification process for energy production

Task 7. To perform a cost analysis of land application and gasification


Sustainability
Capstone Design
Technology
People

Literature Review

Carbon Cycle



Hydrolysis

Complex organic C→ $C_6H_{12}O_6$

Aerobic respiration

$C_6H_{12}O_6 + O_2 \rightarrow CO_2$

Carbon fixation

$CO_2 \rightarrow C_6H_{12}O_6$

Carbon assimilation

$C_6H_{12}O_6 \rightarrow$ complex organic C

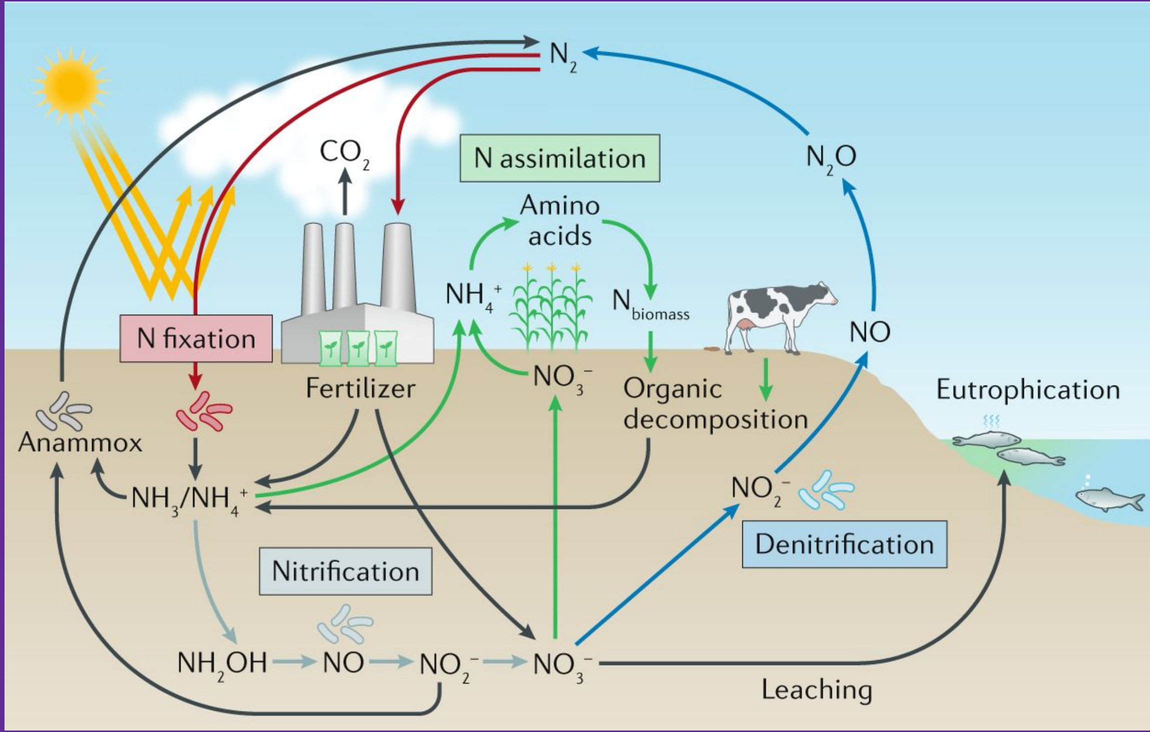
Anaerobic respiration

$C_6H_{12}O_6 + NO_3^- \rightarrow CO_2$

Fermentation

$C_6H_{12}O_6 \rightarrow$ reduced products + CO_2

Microbial Nitrogen Cycle



Nitrogen fixation

$N_2 \rightarrow NH_3 / NH_4^+$

Nitrification

$NH_4^+ \rightarrow NO_3^-$

Assimilative reduction

$NO_3^- \rightarrow NH_4^+$

Denitrification

$Glucose + NO_3^- \rightarrow N_2 + CO_2$

Hydrolysis (ammonification, mineralization)

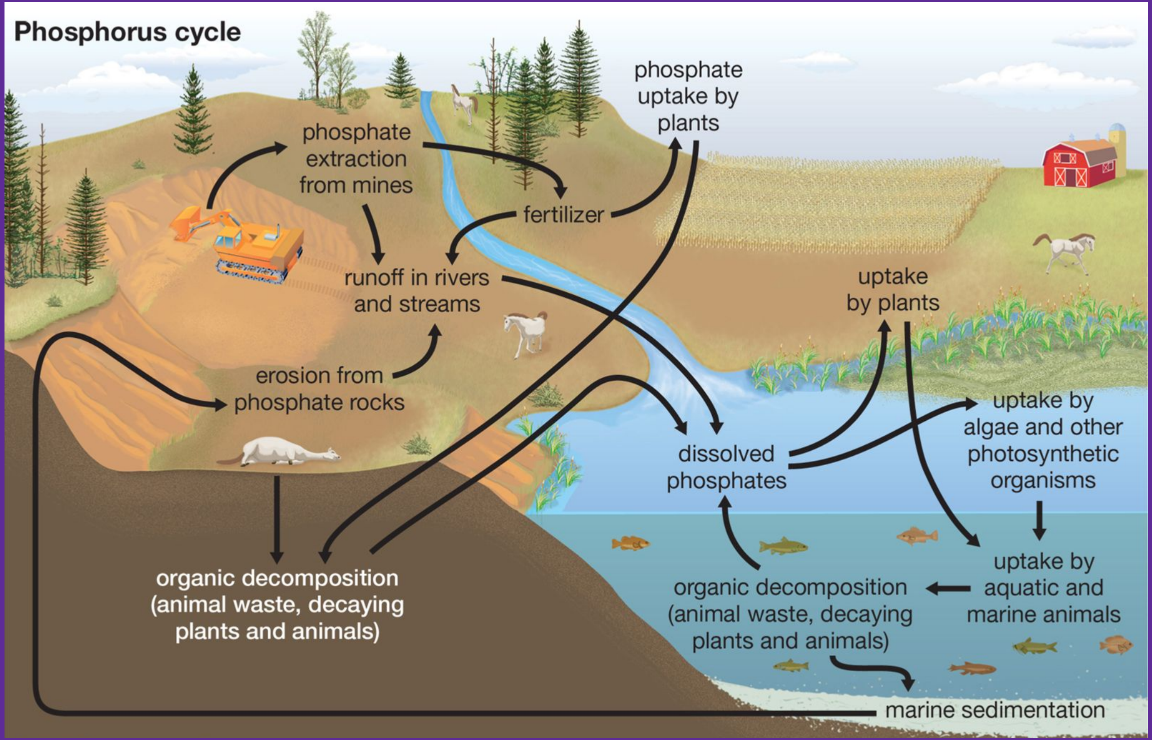
$Organic\ N \rightarrow NH_4^+ / NH_3$

Nitrogen assimilation

Amino acids → protein → cell mass

$NH_4^+ \rightarrow C_5H_7O_2N$

Phosphorus Cycle



Mineralization

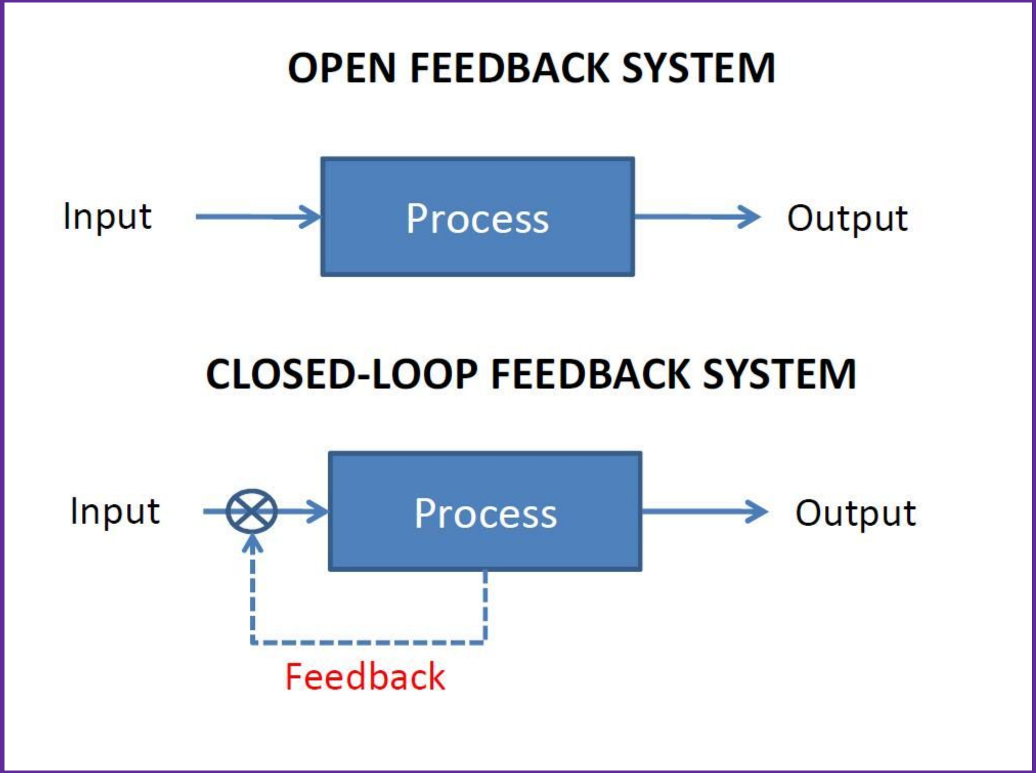
Organic P→ PO_4 3-

Assimilation

$PO_4$3- → Organic P

Elemental Cycles

- Naturally, each cycle is a closed loop system
    - Elements are recycled efficiently
- Landfilling causes process to operate as an open loop system
    - Prevents elements from returning to their source



Land Application

Permitting

- National Pollutant Discharge Elimination System (NPDES) permit
  - Required for wastewater treatment facilities
  - Basic requirements
    - Topographical map of wastewater treatment plant
    - Population that contributes to the wastewater
    - Facility’s design maximum flow
    - Process flow diagram
    - Location and flow rate of effluent wastewater

Permitting

- SC Department of Health and Environmental Control (SCDHEC) permit
    - Required to land apply biosolids in South Carolina
    - Requirements
        - Qualitative
            - Continuous or intermittent application
            - Location of application size
        - Quantitative
            - Biosolid concentrations of Kjeldahl N, inorganic N, ammonia N, P and K
            - Effluent pH, temperature, cyanide concentration, total phenols, residual chlorine, oil & grease concentrations, and fecal coliform levels
            - Average daily volume (gpd) applied to site
            - Heavy metal concentrations
            - Area of the application site
            - 5-day BOD test

Regulations

- Maximum allowable heavy metal concentrations for land applied biosolids

Pollutant	Ceiling Concentration (mg/kg dry weight basis)
Arsenic	75
Cadmium	85
Copper	4300
Lead	840
Mercury	57
Molybdenum	75
Nickel	420
Selenium	100
Zinc	7500

dhec

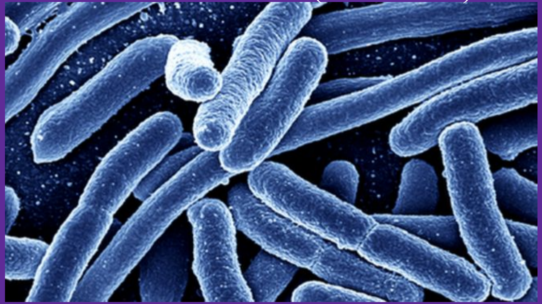
Regulations

- Regulation 61-9: Water Pollution Control Limits
    - Biosolids cannot be land applied
        - If likely negatively affect threatened/endangered species under section 4 of Endangered Species Act
        - If runoff into a wetland or other waters of SC
        - If within 10 meters of a body of water of SC
        - If applied at a rate greater than the agronomic rate for the biosolids (for agricultural fields)

Regulations

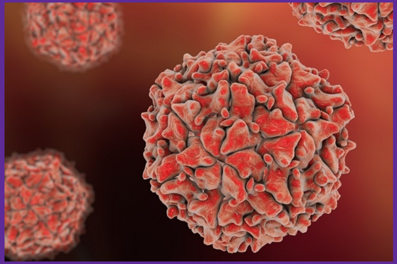
- **Pathogens:** disease-causing organisms, such as certain bacteria, viruses, and parasites

Fecal coliforms (ex. *E. coli*)



Salmonella sp.

Enteric viruses (ex. *Poliovirus* sp.)



Viable helminth ova (ex. *Ascaris lumbricoides*)

Regulations

- Part 503 of the Clean Water Act (CWA)
- Classification of biosolids: Class A or Class B
  - **Class A:** contain pathogen concentrations below detectable limits
    - Can be land applied without further vector regulation
    - Multiple methods to achieve class A status
    - Processes to further reduce pathogens (PFRPs)
  - **Class B:** contain maximum of 1-2 million MPN per 4 gram per dry weight, or 100 mL per wet weight basis, of fecal coliforms
    - Requires further vector regulations
    - Multiple methods to achieve class B status
    - Processes to significantly reduce pathogens (PSRPs)

Options for Pathogen Reduction

- Class A: Alternative 1
  - Thermally treated sewage sludge
    - For biosolids of 7% solid or more, temperature of biosolids increased to 50℃ for a minimum of 15 s
    - Con: energy intensive
    - Con: a polymer is required
- Class B: PSRP
  - Lime stabilization
    - Raise pH of biosolids to 12 for at least 2 hrs
    - Con: socially unsustainable because odor emitted when pH reduced
    - Con: kills beneficial microorganisms in the soil if pH is not reduced prior to land application
  - Anaerobic digestion
    - Residence time of 15 days at 35°C or 60 days at 20°C
    - Con: reverting to an inconsistent previous process
    - Con: low gasification producer gas from anaerobically digested feedstocks

Regulations

- **Vectors:** organisms or objects that transfer pathogens
- 40 CFR Part 503 of CWA
    - Vector attraction reduction (VAR) strategies
        - Include additional anaerobic or aerobic digestion in a bench-scale unit
        - Use aerobic processes at greater than 40°C for 14 days or longer
        - Add alkaline materials to raise the pH under specified conditions
        - Dry biosolids with unstabilized solids to a minimum of 90% solid
        - Dry biosolids without unstabilized solids to a minimum of 75% solid

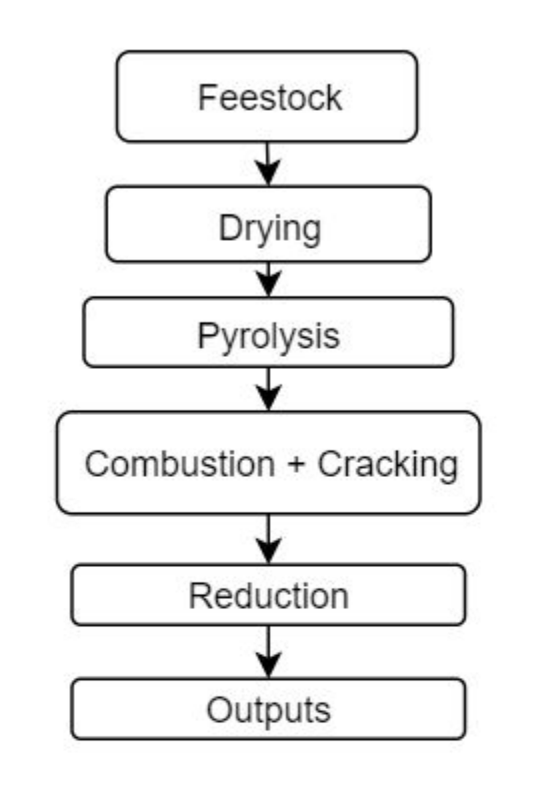
Additional Constraints

- No regulations to control the application of the following compounds
  - Pharmaceuticals
  - Hormone disruptors
  - Microplastics
  - PFAS
  - Patented polymer flocculant
- Site restrictions for Class B
  - Animals can not graze on the land until 30 days after land application
  - Humans cannot access site for 30 days

Gasification

Gasification Process Overview

- Input
  - Biomass
  - Air
- Processes
  - Drying
  - Pyrolysis
  - Combustion/Cracking
  - Reduction
- Outputs
  - Producer gas
  - Ash
  - Biochar
  - Impurities
- Partial combustion



Feedstocks

Biosolids

Coal

Wood chips

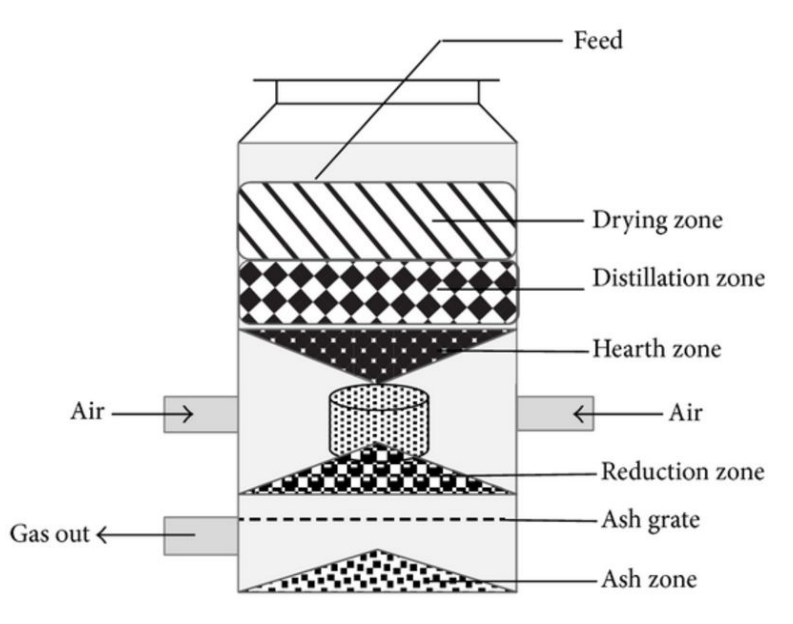
Coke

Pelletization

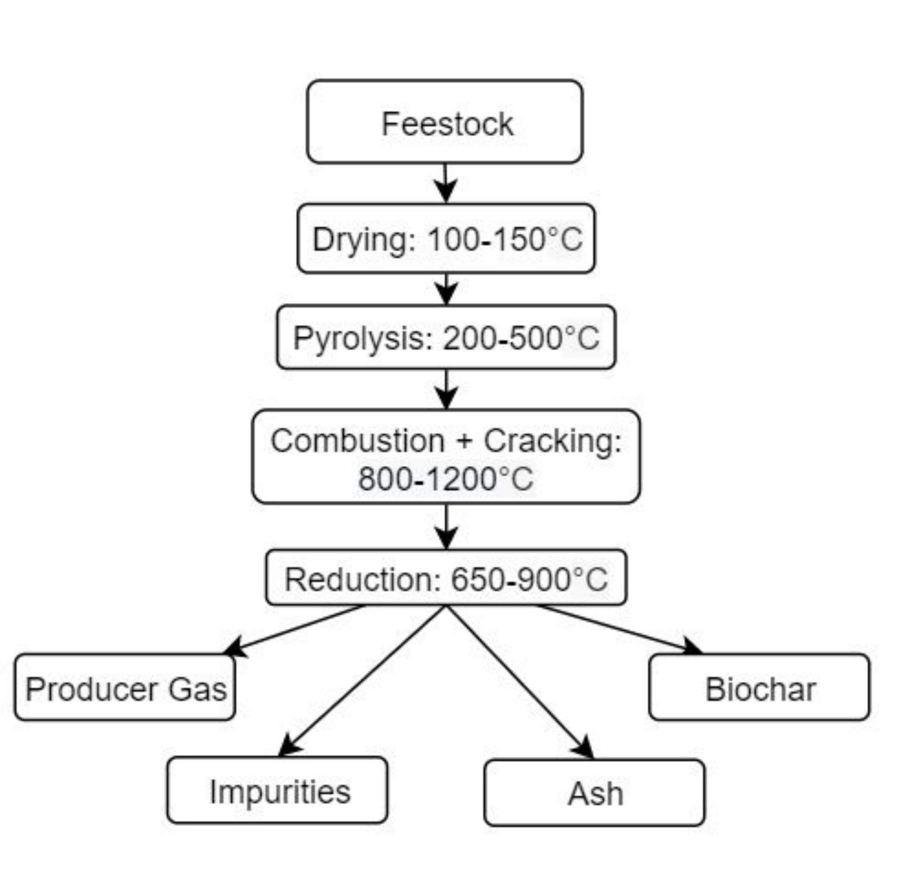
- Pretreatment
  - Select feedstock
  - Filtrate
  - Store
  - Dry to 8-10% water content
  - Crush to consistency
- Process
  - Die and roller compress
  - Lignin and resins act as binding agent
  - Binding agent addition
- Post treatment
  - Cooled and stored
- Easy and cost effective
- Energy dense and normalized feedstock

Downdraft Gasification

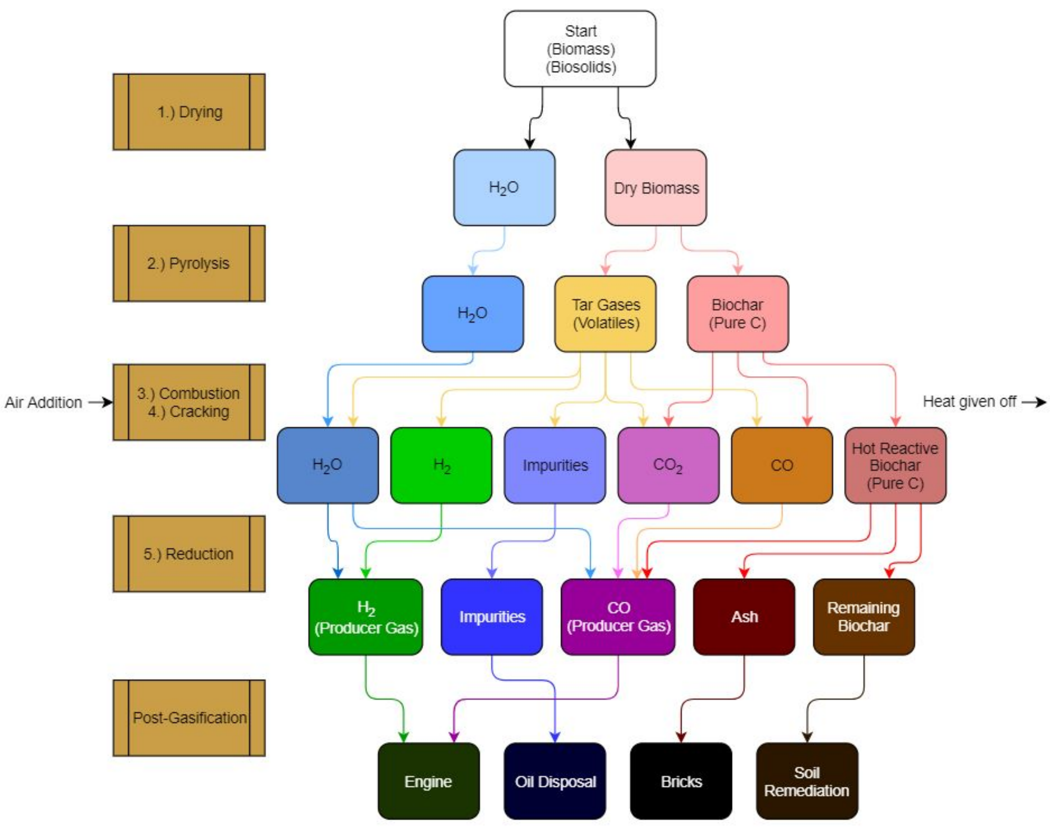
- Clemson University owns an unused downdraft gasifier
  - Co-current flow
  - Normalized feedstock size and known nutrient compositions
  - Outputs
    - Producer gas
    - Impurities
    - Biochar
    - Ash
  - High effluent gas temperature
    - Thermodynamically unfavorable
  - Possibly carbon negative or neutral
- Several gasification processes exist



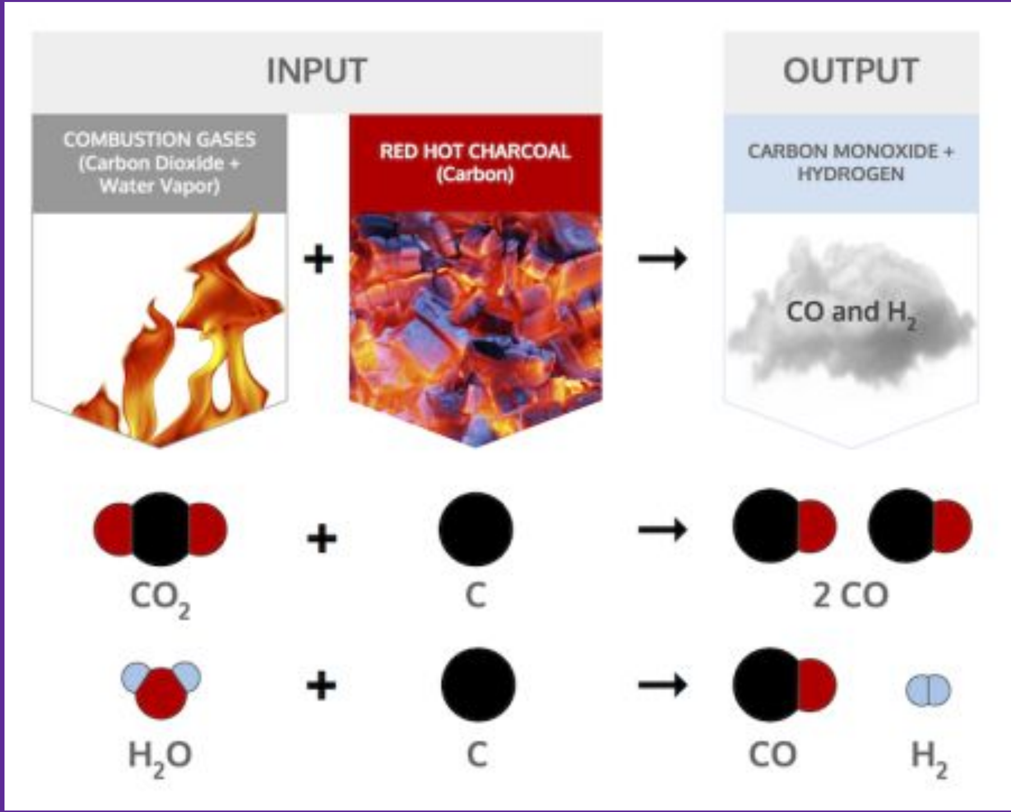
Process Overview

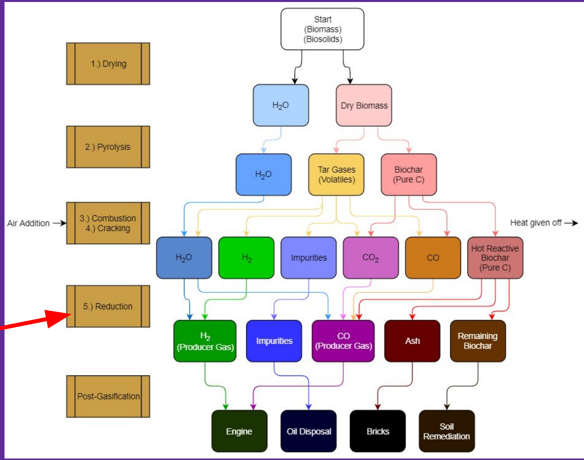


Process Overview



Reduction


INPUT
COMBUSTION GASES (Carbon Dioxide + Water Vapor)
RED HOT CHARCOAL (Carbon)
OUTPUT
CARBON MONOXIDE + HYDROGEN
CO and H2
CO2
C
2 CO
H2O
C
CO
H2


Start (Biomass) (Biosolids)
1.) Drying
H2O
Dry Biomass
2.) Pyrolysis
H2O
Tar Gases (Volatiles)
Biochar (Pure C)
Air Addition
3.) Combustion 4.) Cracking
Heat given off
H2O
H2
Impurities
CO2
CO
Hot Reactive Biochar (Pure C)
5.) Reduction
H2 (Producer Gas)
Impurities
CO (Producer Gas)
Ash
Remaining Biochar
Post-Gasification
Engine
Oil Disposal
Bricks
Soil Remediation

Reactions

Oxidation zone

$$C + O_2 \rightarrow CO_2, \ \Delta H = -406 \ \text{kJ/mol}$$

$$2C + O_2 \rightarrow 2CO, \ \Delta H = -123 \ \text{kJ/mol}$$

Reduction zone

$$C + CO_2 \rightarrow 2CO, \ \Delta H = 162 \ \text{kJ/mol}$$

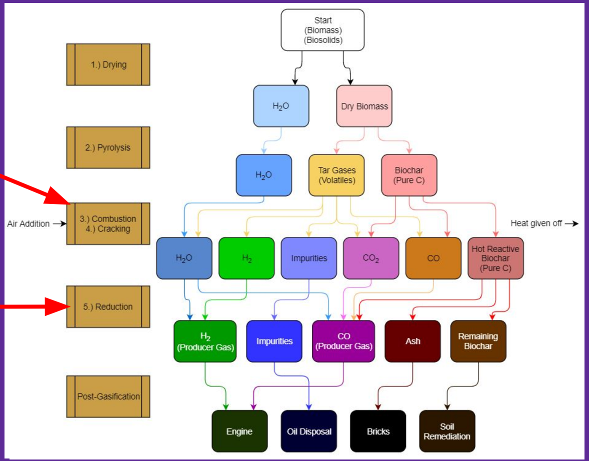
$$C + H_2O \rightarrow CO + H_2, \ \Delta H = 119 \ \text{kJ/mol}$$

$$C + 2H_2O \rightarrow CO_2 + 2H_2, \ \Delta H = 75 \ \text{kJ/mol}$$

$$C + 2H_2 \rightarrow CH_4, \ \Delta H = -87 \ \text{kJ/mol}$$

$$CO + H_2O \rightarrow CO_2 + H_2, \ \Delta H = -42 \ \text{kJ/mol}$$

$$2C + 2H_2O \rightarrow CO_2 + CH_4, \ \Delta H = -11 \ \text{kJ/mol}$$



Products

Producer gas - 46.6%

- Combustible gases - 22.5%
  - CO
  - H_2
  - CH_4
  - C_mH_n
- Oxidized & inert gases - 24.1%
  - CO_2
  - H_2O
  - N_2

Solids - 53.3%

- Biochar - 4.2%
  - Low porosity
  - Crystalline structure
  - Stores carbon if added to soil
- Ash - 49.1%
  - Powder form
  - Heavy metals
  - Minerals
    - Na, Ca, K, etc.
  - C, H, O, and N absent

Impurities - <0.1%

- Tar gases & condensable liquids
  - Sulfur & nitrogen compounds
  - Hydrogen halides
  - Aromatics
    - Benzene, toluene, etc.

Materials and Methods

Dewatering & Drying of Biosolids

Starch Based Polymer

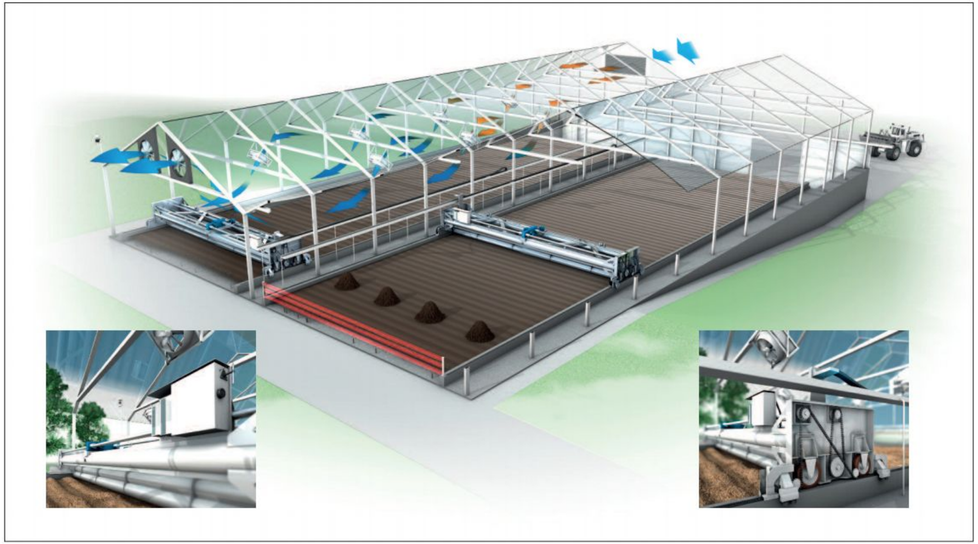
- Polyacrylamide-free Flocculant (PAMf-FCC)
  - Produced by the Biomass Conversion and Water Technology in Germany
  - Environmental friendly
  - High biodegradability
  - Amphiphilic
    - Enables binding of contaminants
  - More research and development necessary before on the market

I – Commercial Cationic Starch

II – Cationic PAMf-FCC

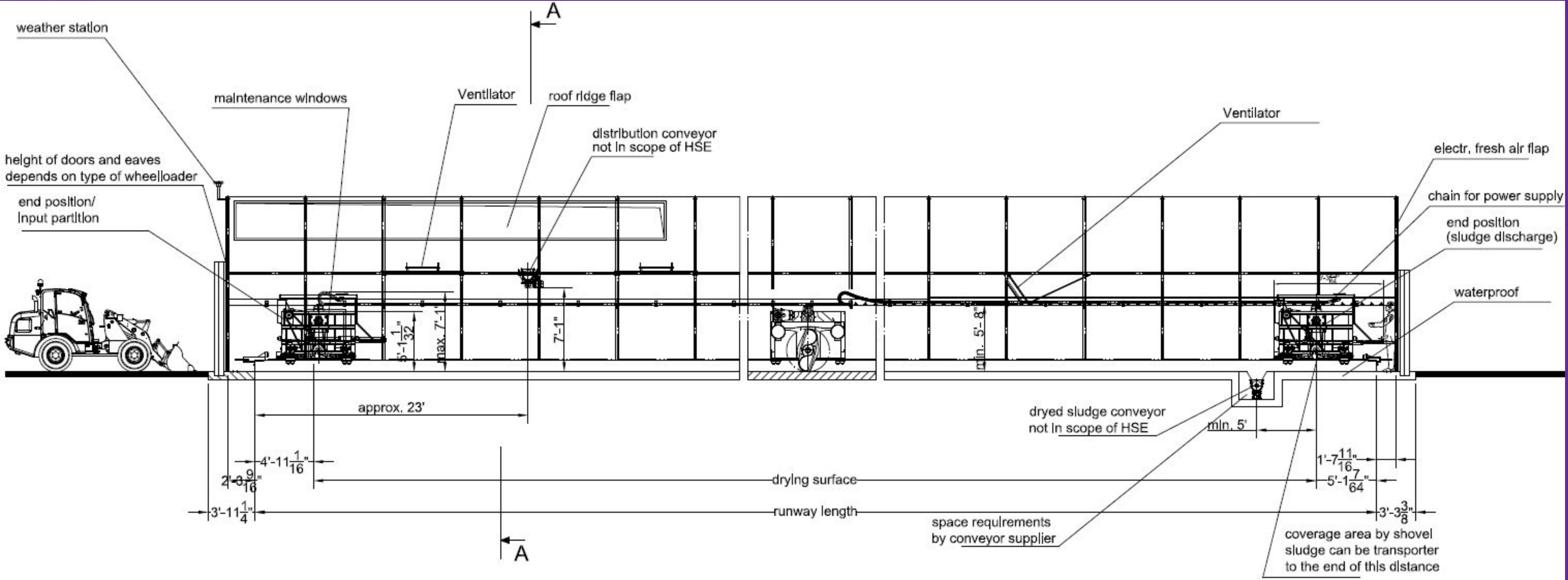
HUBER Sludge Turner SOLSTICE

- Facility dimensions: 185 ft x 40 ft
- Biosolid bed width: ~36 ft
- Biosolid bed length: ~163 ft
- Depth: 1 ft
- Max. volume of biosolids: 5868 ft^3
- Temp: 30°C - 40°C
- RT: 2-3 weeks to reach 90% solid
- Automatic or manual biosolid loading & unloading
- Potential upgrades
  - Increase max. temperature
  - Odor scrubber
  - Powered by non-renewable energy sources



HUBER SRT system – solar sewage sludge drying with the HUBER Sludge Turner SOLSTICE®

HUBER Sludge Turner SOLSTICE



Methods

- Chose a location for the solar dryer
- Determined volume needed in solar dryer to hold flow of biosolids
- Calculated a mass flow rate of biosolids two standard deviations above the mean

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

- s = standard deviation
- N = number of observations
- x_i = observed values
- $\bar{x}$ = average value

Land Application of Biosolids

Materials

- Terragator
- Biosolid storage tank
- Simpson Research Farm fields

Methods

- Measured current pathogen concentration in biosolids with lab testing of MPN
- Selected lands within Simpson Research Farm based on EPA & SC DHEC regulations
- Collected soil samples within Simpson Research Farm
- Calculated acceptable biosolid volume to be land applied based on nutrient concentrations in the soil & biosolids, area of land, and agronomic rate of crop
- Chose pathogen reduction method
  - Alternative 1. thermally treated biosolids

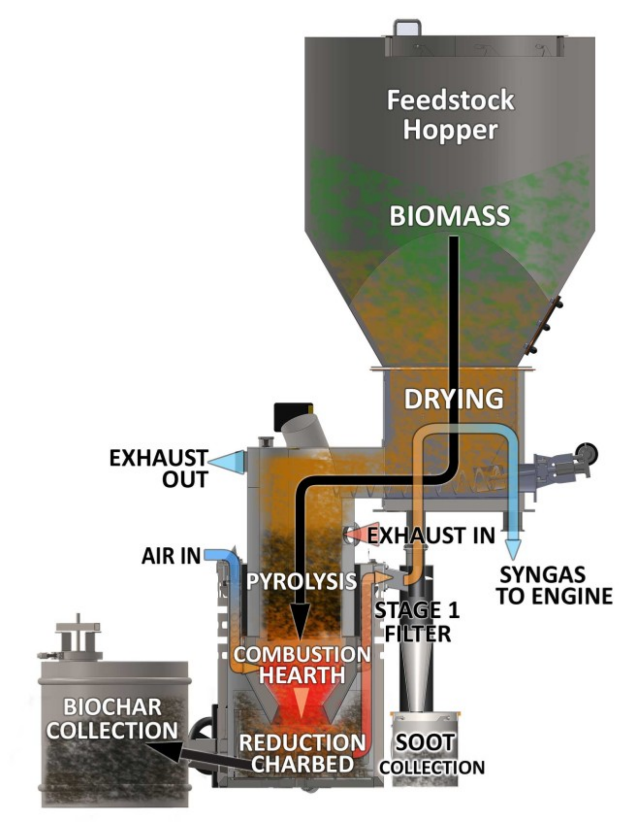
$$D = 131{,}700{,}000 / (10^{0.14t})$$

- Chose VAR
- Land apply biosolids with terragator

Gasification of Biosolids for Energy Production

Materials: California Pellet Mill CL Type 3

Materials: All Power Labs PP20 Power Pallet



Methods

- Quantified mass flow rates of biosolids through the process
- Determined the amount of wood chips necessary for pelletization
- Observed a storage tank was needed for the wood chips
  - Derived dimensions
  - 4 purchases of wood chips over the year
- Measured moisture content of wood chips at the Cherry Crossing Compost Facility
- Calculated the outputs of gasification
- Estimated the amount of energy produced

Methods: Feedstock Parameters

$$m_P = m_b + m_{wc}$$

Solid content before pellitization: $0.95(m_b) + 0.83(m_{wc}) = 0.91(m_p)$

Lignin: $0.1(m_b) + 0.25(m_{wc}) = 0.15(m_p)$

$$\rho_T = \left(\frac{m_w}{m_T}\right)(\rho_w) + \left(\frac{m_{wc}}{m_T}\right)(\rho_{wc}) + \left(\frac{m_b}{m_T}\right)(\rho_b)$$

- m_p = mass of solids before pelletization (lb)
- m_b = mass of biosolids (lb)
- m_{wc} = mass of wood chips (lb)
- m_w = mass of water (lb)
- m_T = total mass (lb)
- ρ_T = total density (lb/ft^3)
- ρ_w = density of water (lb/ft^3)
- ρ_{wc} = density of wood chips (lb/ft^3)
- ρ_b = density of biosolids (lb/ft^3)

Methods: Energy Production

$$Q_{combustion} = \frac{m_{gas} * \Delta H_{combustion} * \eta_{engine} * \eta_{generator}}{3600}$$

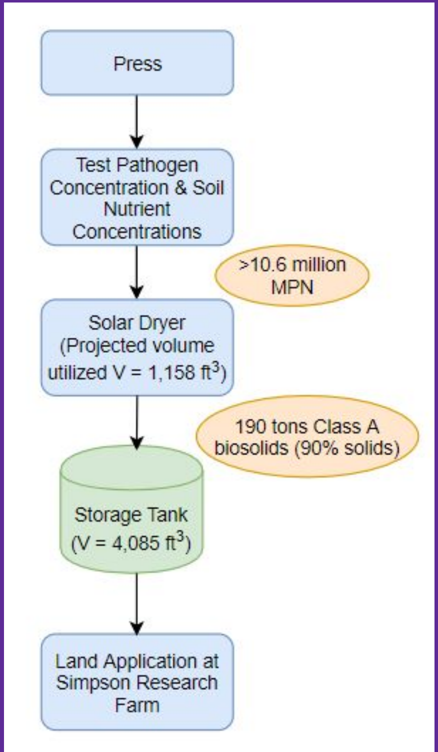
$$C = Q_{combustion} * P$$

- $Q_{combustion}$ = energy of combustion (kwh)
- m_{gas} = mass of gas (kg)
- $\Delta H_{combustion}$ = heat of combustion of the gas (kJ/kg)
- η_{engine} = efficiency of the engine (-)
- $\eta_{generator}$ = efficiency of the generator (-)
- C = equivalent cost of energy ($)
- P = price of electricity ($/kWh)

Results

Land Application

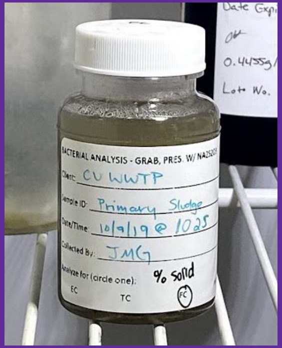
Process Flow Diagram



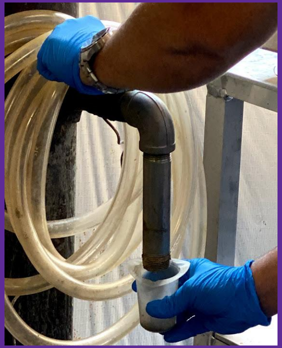
Fecal Coliform Tests

	Fecal Coliform (MPN/g dry wt)
Primary Digester	597,000,000
Secondary Digester	1,720,000
Dewatered Sludge	10,600,000

- Do not meet Class B classification
  - 10.6 million MPN > 0.5 million MPN

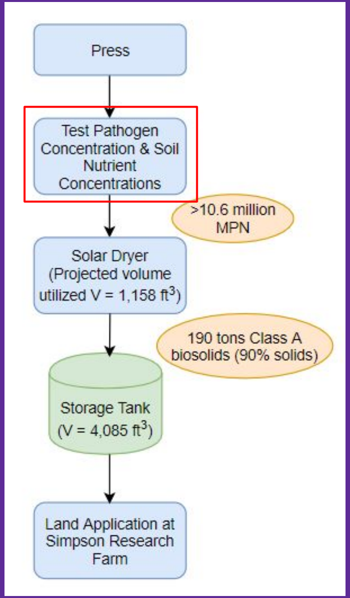


Primary Sludge

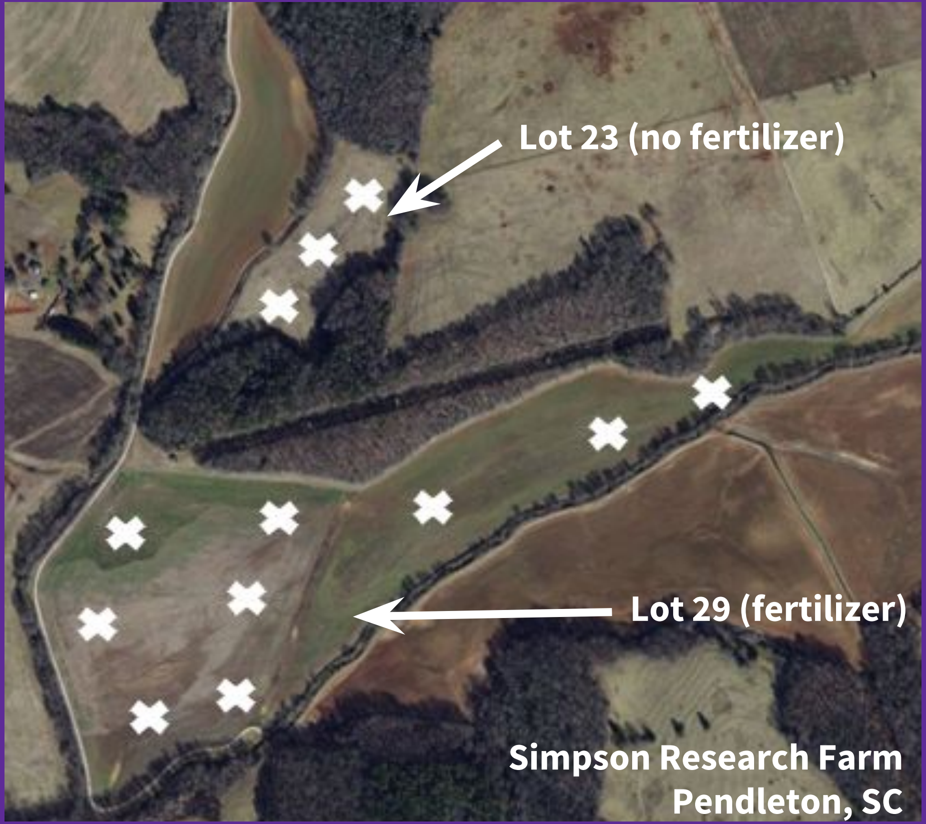


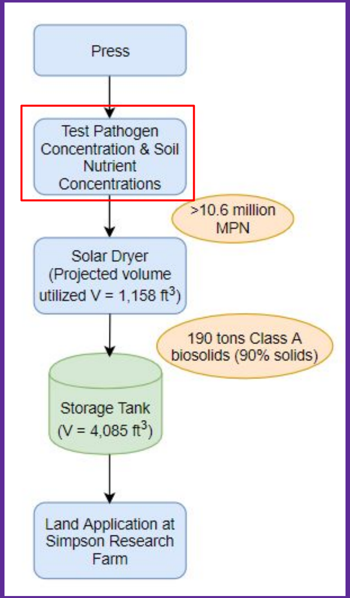
Secondary Sludge

Dewatered Sludge



Soil Sampling Area



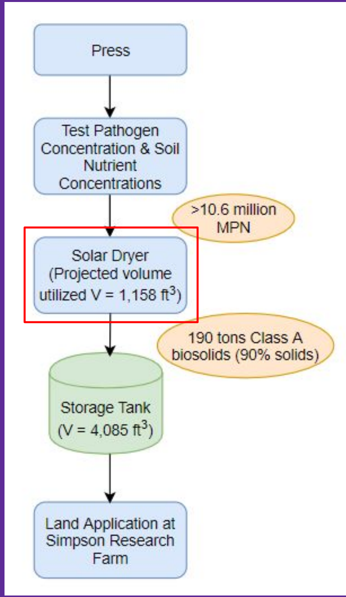


Soil Testing

	Soil pH	P (lbs/A)	K (lbs/A)	Ca (lbs/A)	Mg (lbs/A)	Zn (lbs/A)	Mn (lbs/A)	Cu (lbs/A)	B (lbs/A)	Na (lbs/A)	NO_3-N (lbs/A)
Lot 23 (no fertilizer)	5.76	3.67	302.00	920.00	279.00	3.50	32.00	0.47	0.60	10.00	1.67
Lot 29 (fertilizer)	5.98	24.60	125.00	1454.00	373.00	5.31	39.80	1.68	0.46	16.40	32.90

Solar Drying System

- Incoming biosolids 951 tons of 18% dry weight
- Solar dryer uses combination of convection, conduction, and radiation
  - Dries solids from **18% to 90%** dry weight
- Products
  - 190 tons of Class A biosolids (90% solids)
  - 761 tons of water
- Achieves pathogen & vector reduction
  - Heat biosolids to min. of 50℃ for at least 20 minutes
  - Dry biosolids with unstabilized solids to a minimum of 90% solid
  - Dry biosolids without unstabilized solids to a minimum of 75% solid

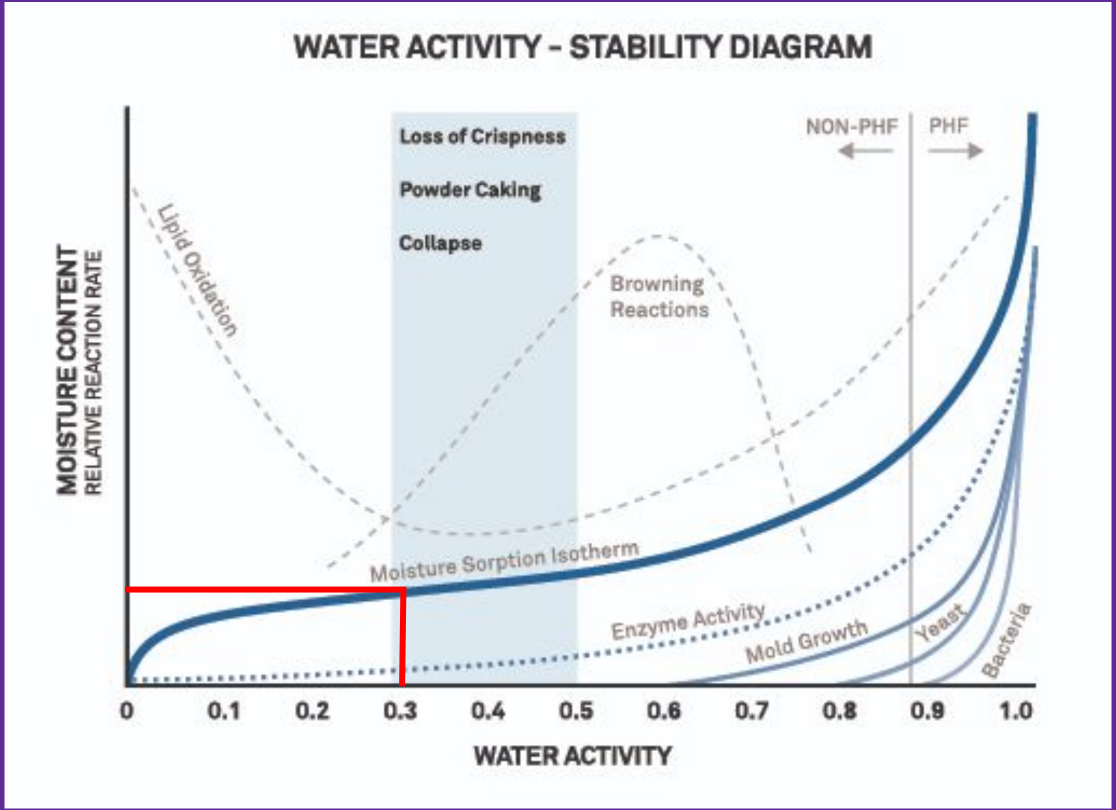


$D = 131{,}700{,}000 / (10^{0.14t})$

$t = 50°C$, $D = 13.17$ days

	Entering Water Mass (tons)	Retained Water Mass (tons)	Lost Water Mass (tons)
Press	8387.82	779.82	7,608.00
Solar Dryer	779.82	19.02	760.80

Water Activity



Storage Tank

Calculations for storage tank dimensions

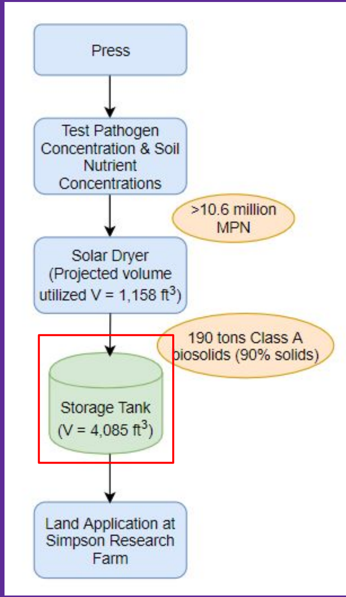
- Projected amount of biosolids produced in future = 951 tons
- Volume of 90% dry biosolids produced = 8,135.7 ft^3
- Required storage volume = 4,067.8 ft^3
- Storage tank dimensions

  Choose radius = 10 ft

$$V = \pi * r^2 * h$$
$$4{,}067.8\ ft^3 = \pi * (10\ ft)^2 * h$$
$$h = 12.9\ ft$$

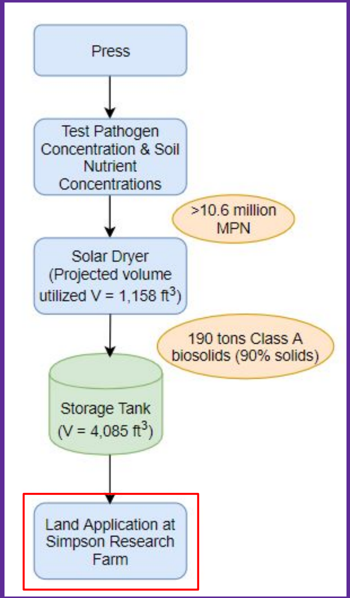
$$V = 4{,}085\ ft^3$$
$$r = 10\ ft$$
$$h = 13\ ft$$

Aerial view of CU WWTP



Application of Biosolids

- Eligible fields within Simpson Research Farm
  - 90.54 acres of Bermuda pasture
  - 530.34 acres of Fescue pasture
- Agronomic rate of nitrogen for Bermuda and Fescue grasses
  - 1.66 tons of CU WWTP dry biosolids/acre/yr
- Application rates
  - Maximum 150 tons dry biosolids/yr to Bermuda pastures
  - Maximum 881 tons dry biosolids/yr to Fescue pastures
  - Maximum 1,031 tons dry biosolids/yr to Simpson Research Farm
- Application schedule
  - Fall: apply to Bermuda pastures
  - Spring: apply to Fescue pastures



Pros & Cons of Land Application

Pros

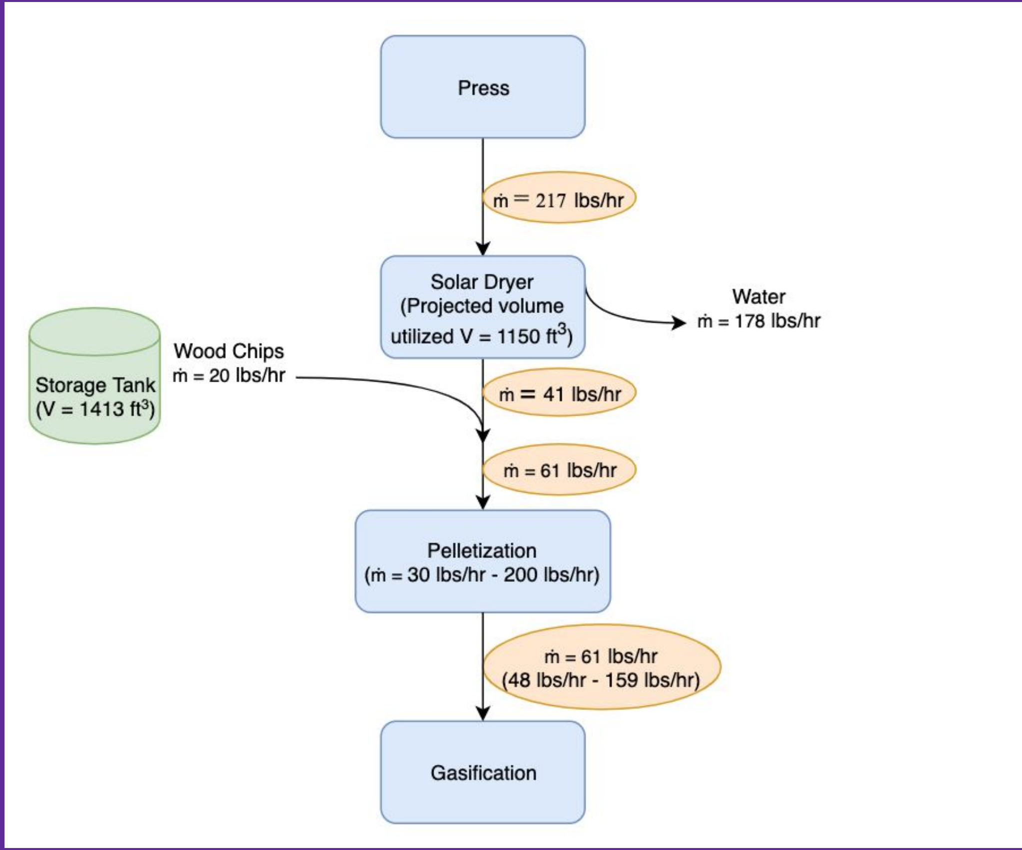
- Increases porosity of soil
  - Increases infiltration rate
  - Increases water holding capacity
  - Decreases rate of runoff
- Addition of vital nutrients to soil
  - C, N, P
- Capable of land applying 1,031 tons of dry biosolids/yr
  - Accommodates an increase in student population

Cons

- Possible nutrient leaching into groundwater
- Potential runoff into nearby bodies of water due to extreme weather events
- Effects of pharmaceuticals, hormones, and microplastics on soil unknown
- Purchase 2,828 ft^3 storage tank necessary

Gasification

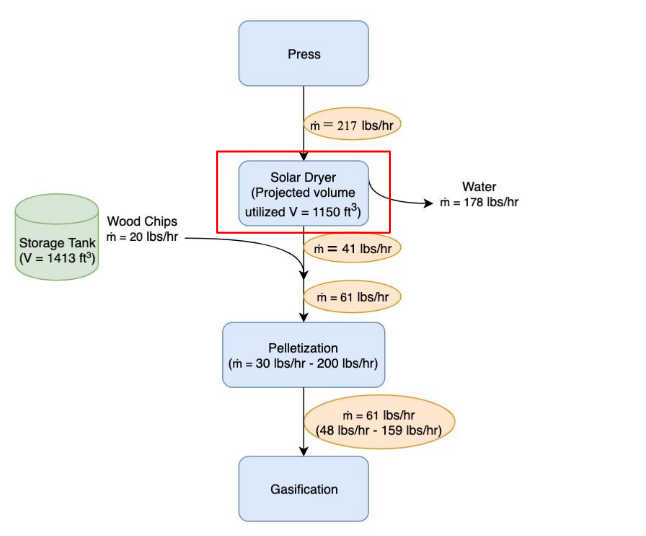
Process Flow Diagram



Dryer

- Incoming biosolids at 951 tons of 18% dry weight
- Solar dryer uses combination of convection, conduction, and radiation
  - Dries solids from **18% to 95%** dry weight
  - 2-3 week retention time
- Products
  - 180 tons of solids
  - 771 tons of water

	Entering Water Mass (Tons)	Retained Water Mass (Tons)	Lost Water Mass (Tons)
Press	8,387.82	779.82	7,608.00
Solar Dryer	779.82	9.01	770.81



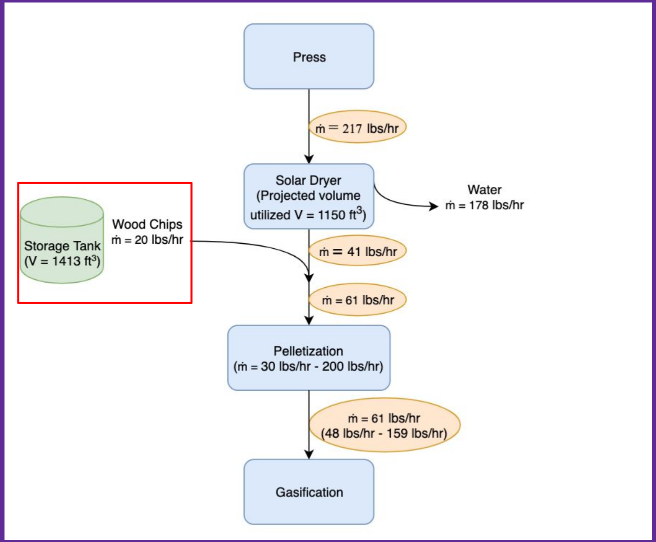
Wood Chip Lab Testing

- Moisture content of the wood chips
- Concluding the wood chips would be 83% dry
  - It rained soon before the sample
  - Only wood chips from the top will be sent to the pelletization process
  - Surrounded storage facility

Sample	Percent Solid
Dry Wood Chips from the Front	81%
Dry Organic Matter from the Front	83%
Wet Wood Chips from the Front	48%
Wet Organic Matter from the Front	35%
Dry Wood Chips from the Back	79%
Dry Organic Matter from the Back	80%
Wet Wood Chips from the Back	63%
Wet Organic Matter from the Back	64%

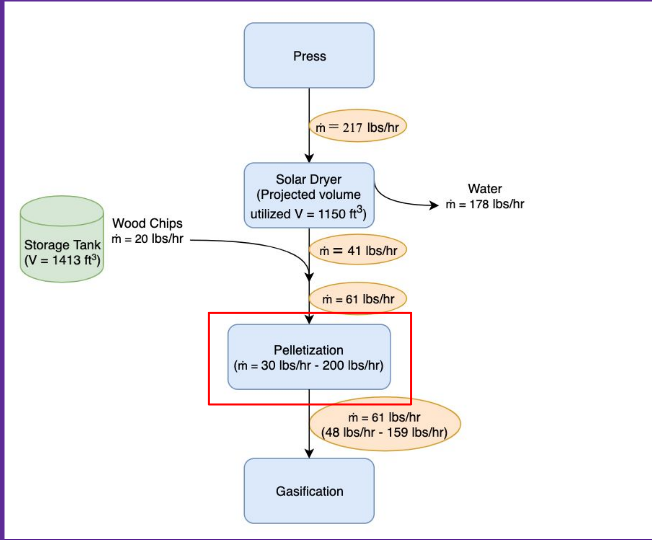
Wood Chip Storage

- 20 lbs/hr wood chip addition to biosolids to satisfy lignin and moisture equations
- Total amount of wood chips per year
  - 86 tons (171,180 lbs)
  - Density of 30 lbs/ft^3 get total volume
  - Purchase 4 times a year
- Storage tank volume of 1,413 ft^3 (10,570 gal)
  - 11,000 gal storage tank purchased



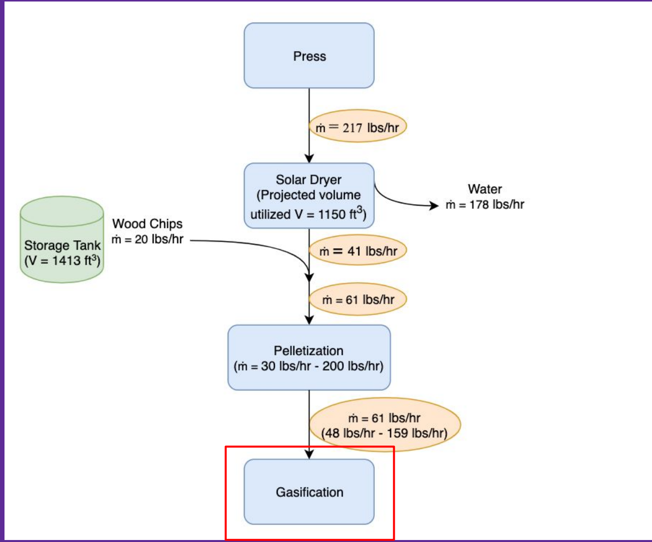
Pelletizer

- Inputs projected from 2019 flow of biosolids
  - Total mass flow: 61 lbs/hr with 15% lignin and 91% solid content
  - Solids: 41 lbs/hr with 10% lignin and 95% solid content
  - Wood chips: 20 lbs/hr with 25% lignin and 83% solid content
- Product
  - Pellets production of density 41 lbs/ft^3 at 61 lbs/hr
    - Pelletizing rate of equipment is between 30 - 200 lbs/hr



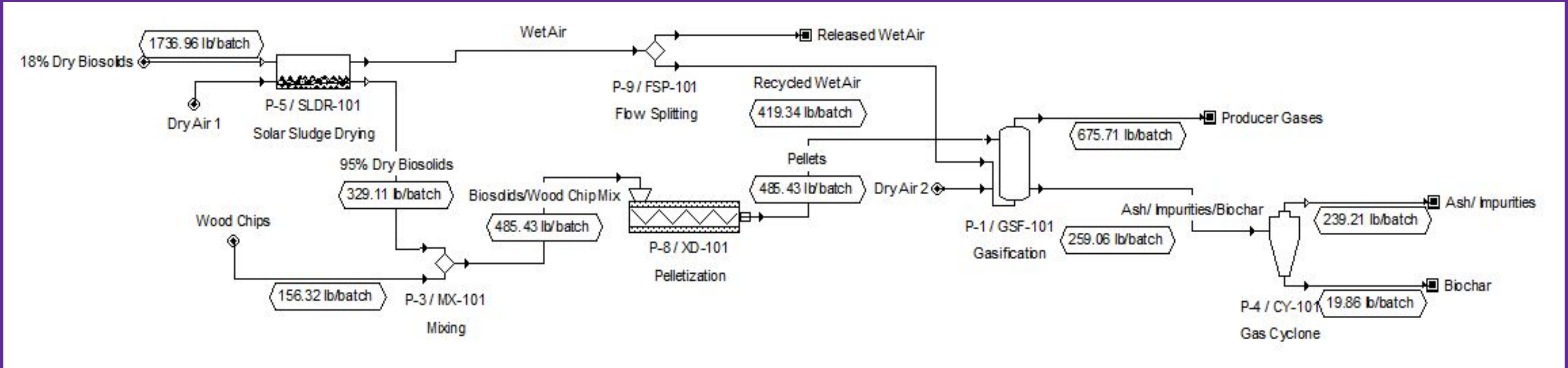
Gasifier

- Feedstock
- Batches
    - Volume of vessel: 11.65 ft^3
    - Number of batches: 1,079 cycles
    - Batches per day: 3 cycles
    - Duration of batch: 8 hrs
    - Operates 350 days of the year
- Recycling waste
    - Solar dryer
        - Water vapor inlet to pyrolysis chamber to reduce solid content to 70% to 90% to prevent overheating
    - Waste heat utilized for dryer
    - Supplemental electricity to power dryer and pelletizer



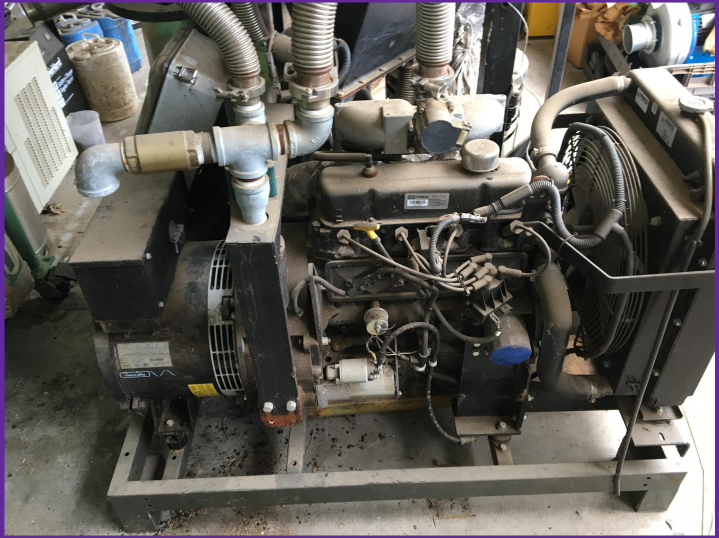
Gasifier

- One of the two gasification agent intakes would be connected with this recycled air from the solar dryer
- The connected intake would pull in the wet air as necessary
- Amount of air recycled from the dryer is 52 lbs/hr
- With recycled air, the biosolids are now 81% solid
    - Within desired 70 to 90% solid content range



Gasification: Engine

Compound	Percent Gas Produced	Enthalpy (kJ/kg)
H_2	18.12%	141,584.00
CO	15.44%	10,100.00
CH_4	9.20%	55,514.00
C_mH_n	0.50%	~ 50,285.00



Gasification: Generator

Compound	Energy (kWh)
H_2	23,226.82
CO	1,411.84
CH_4	4,623.89
C_mH_n	2,412.86
Total	31,675.41

Pros & Cons of Gasification

- Pros
  - Turns a current waste material into an energy source
    - 31,675 kWh/year
    - Equivalent to $2,534
    - Creates a clean gas
    - Potentially carbon neutral
  - Production of high heat biochar and ash
    - Brick and concrete formation
    - Soil remediation
      - PFAS reduction
  - Carbon storage
    - 7.6 tons of C sequestered as biochar from 951 tons of biosolids

- Cons
  - Increased workload
    - Removal of biochar and ash
    - Additional employees required
    - Inconvenient working hours
    - Continuous operation for 350 days
  - Production of impurities
    - Tar gas
  - High levels of waste heat
    - Thermodynamically unfavorable
  - Large quantities of wood chips used
  - Regulations and handling
    - EPA emissions permits
    - Record keeping
    - OSHA worker health safety

Economic Analysis

Economic Analysis: Landfill

Item	Capital Cost	Annual Cost	Operating Cost	Total Cost
Press	$0	$6,554	NA	$6,554
Polymer	$0	$11,844	$6,980	$18,824
Landfill Deposits 2018	NA	$21,787	NA	$21,787
Projected Landfill Deposits 2019	NA	$30,661	NA	$30,661
			Total Cost 2018	$47,165
			Total Cost 2019	$56,039

Economic Analysis: Land Application

Item	Capital Cost	Annual Cost	Operating Cost	Total Cost
Press	$0	$6,554	NA	$6,554
Starch Polymer	$0	$1,215	$6,980	$8,195
Solar Dryer	$1,000,000	NA	$55,840	$1,055,840
Storage Tank (500 gal)	$432	$0	$0	$432
Storage Tank (30,000 gal)	$25,473	$0	$0	$25,473
			Total Cost for First Year	$1,096,494

Economic Analysis: Gasification

Item	Capital Cost	Annual Cost	Operating Cost	Total Cost
Press	$0	$6,554	NA	$6,554
Starch Polymer	$0	$1,215	$6,980	$8,195
Solar Dryer	$1,000,000	NA	$55,840	$1,055,840
Solar Dryer Upgrades	$350,000	$0	$0	$350,000
Wood chips	$0	$151,475	$0	$151,475
Wood chip storage	$7,899	$0	$0	$7,899
Pelletizer	$0	$2,498	$0	$2,498
Gasifier	$0	$812	$167,520	$168,332
			Total Cost for First Year	$1,750,793

Economic Analysis: Overview

	Landfilling	Land Application	Gasification
Initial Investments	$0	$1,025,905	$1,365,998
Annual Operational Cost	$56,039	$70,589	$392,895
Annual Income	$0	$0	$2,534
Total Cost for First Year	$56,039	$1,096,494	$1,756,359

Take Home Messages

Recommendation

- Land application of biosolids for soil fertilization
  - Utilize a starch based polymer
  - Purchase an environmentally friendly solar dryer
    - Train operator to run solar dryer
  - Store dried biosolids in a tank until application at Simpson Research Farm

- Rationale
  - Gasification is too expensive, possibly dangerous, and produces toxic impurities
  - Organic fertilizer utilized instead of synthetic
    - Reduces anthropocentric inputs of nitrogen
  - Simpson Research Farm is capable of processing more biosolids than the projected amount produced at the CU WWTP
  - Costs $14,000 more per year to land apply than landfill

Research regarding the effects of pharmaceuticals, hormone disruptors, microplastics and PFAs on the environment MUST be conducted before the biosolids are land applied.

Sustainability

Technology

People

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Don't waste your waste!

Thank you!