Project Report

CHEN E4380 Green Chemical Engineering and Innovation

Group 6

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Table of Contents

Table of Figures

1. Executive Summary

At its core, our proposal seeks to address the challenge of transporting feedstock for bioprocessing efficiently and sustainably. We focus on integrating fermentation processes into transportation infrastructure. We want to make sure that every step of the journey, from farm to factories is as efficient and eco-friendly as possible. By doing this, we're not just making things easier for ourselves but we're also unlocking the potential of bio-based materials like PHA, which can make a big difference in the world of eco-friendly packaging.

Our solution integrating rectors with transportation also includes trucks, trains and if the situation is right even on ships. The reactors that we provide have all the technology to smoothly run the fermentation while being transported and with limited human interference.

Benefits:

1. Lower Carbon emissions
2. Continues process
3. Increasing bio process efficiency

Along with all these benefits our solution the degradation of the feedstock during transportation is almost negligible as the process starts at the farm or the source of the feedstock. This gives us a chance to implement our technology while the Farmers get a new opportunity to sell their crops and processing plants to save money on transportation. But making this vision a reality won't be easy. It's going to take a lot of resources, time, money, and effort. We'll need to invest in research, upgrade our infrastructure, and get everyone on board with the plan. It's a big undertaking, but with the right timeline and budget in place, we're confident we can make it happen with our diverse team of engineers.

We are confident that this project presents a unique opportunity for sustainable growth across various industries. To turn this vision into reality, we invite potential partners and investors to join us in shaping the future of bioprocessing and next gen reactors.

2. Introduction to Problem

Transporting feedstock for bio-packaging and other bioprocesses from farms or different locations to primary processing plants is a complex task. This effort takes up time and money, so it should be done as efficiently as possible. However, care must be taken to keep the feedstock in good condition while it is being transported because any departure from the right conditions can cause spoilage and therefore reduce the amount of product that can be obtained from it later on. It is found that up to 30% of spoilage can occur during the transportation of feedstocks like sugarcane baggage at extreme conditions (1). With global warming and the 1.5 degree goal set by the COP it is becoming an ever increasing problem every day, emissions produced during transportation represent sustainability challenges of considerable magnitude(2). Climate's unpredictability only serves to further complicate things thereby calling for new ways that will take into account both environmental objectives and transport efficiency requirements.

For instance let us consider how polyhydroxyalkanoates (PHA) could be produced using agricultural feed stocks which originate from farms. PHA can degrade naturally hence used as a substitute for plastics in making bio packages among other things thus showing the potentiality inherent within this particular technique when it comes transforming raw materials into sustainable products . Nevertheless just like any other bioprocessing sector there are logistical challenges involved in transporting farm based inputs used during PHA production processes . Therefore steps must be taken towards solving problems linked with moving such items for PHA production.

3. Solution

In order to address the issue of inefficiency in transportation, our solution that is integrating fermentation processes directly within transportation infrastructure emerges as a promising avenue for addressing these pressing challenges, gives us a unique advantage targeting the fermenter market (automatic fermenter) and the market associated with the chemical that is produced in the fermenter.

For example let's consider the PHA production process below (Figure 1 and Figure 2):

1. Feedstock Sourcing: Agricultural feedstock, such as plant oils or sugars derived from crops like corn or sugarcane, serves as the raw material for PHA production. The transportation of these feedstocks from farms to processing plants marks the initial stage of the PHA production process.

2. Feedstock Preprocessing: Upon arrival at the processing plant, the agricultural feedstock undergoes preprocessing steps to convert it into a form suitable for PHA production. This may involve milling, crushing, or enzymatic treatments to extract the desired components.

3. Fermentation: The preprocessed feedstock is introduced into fermentation tanks where microbial strains capable of producing PHA are cultivated. During fermentation, these microorganisms metabolize the feedstock components, converting them into PHA polymers as intracellular storage materials.

4. Once fermentation is complete, the microbial biomass containing PHA is harvested from the fermentation broth. Various techniques such as centrifugation or filtration are employed to separate the biomass from the fermentation medium.

5. PHA Extraction: The harvested biomass undergoes further processing to extract the PHA polymers from the microbial cells. This typically involves steps such as cell lysis, solvent extraction, and purification to isolate the PHA in its final form.

Our reactors that are placed behind the trucks or trains integrate the fermenters on the 3rd step which is our product. While it can do that it can also be customized to the need between the 2nd and the 3rd step in the process which is enzymatic treatments and fermentation.

In order to create such a reactor that is portable, there are challenges. Our team has come up with the solution to do it safely and efficiently with already existing technologies in the cement, oil and gas industry. Given below are some of the safety considerations:

1. For Leaks and Spills our product will have Double containment systems with leak detection.
2. For Pressure Build-up in reactors we will Continuously monitor pressure levels during operation and set up moving plate pressure regulators
3. For Temperature Control we Insulate the fermenter and set up electric heater
4. For Biological Hazards we use non-pathogenic strains of bacteria for fermentation.
5. For prevention Accidents and Collisions we are going to install baffle or bed to minimize movement during transport

The technologies are sold by some companies, for Leaks and Spills will use AlertLabs detection system and GF piping Systems. For tackling pressure build up and temperature we will use a moving top storage tank system to the fermenter to deal with the increasing pressure and maintain temperature using electric heater which is widely used in transporting liquids. Using Non-pathogenic strains of bacteria for reducing biohazard allows for the reactor to travel through the cities. The last concern is the prevention of accidents which might be caused by the movement of water in the fermenter during transportation. To solve this problem our reactors will be equipped with the already existing technology of baffles which allow for the reduced movement of liquid in the tank. The carbon emissions are lowered compared to traditional by using trucks using bioreactor train and have high capacity. The production of PHA has been significantly increased which yields more profit and PHA is a biodegradable polymer. If we can convert glucose convertible waste into it we can replace traditional plastic and we go to a more green and sustainable environment. Regarding Safety we operate at temperatures of 25-45 C.

The tropical climate in India or any other countries are best operating conditions and at atmospheric pressure we shouldn't worry much about safety. The material and energy input is comparatively less compared to thermos-catalytic processes.

3.1 Quantitative reasoning of integrating reactors with transportation

In order to understand the impact a case study was studied on the Kolhapur district in India. This city produces one of the largest amounts of sugarcane in India and also home to many fermenters for different bioplastic production. We did an analysis of the carbon emission on the PHA production plants in the city to understand the amount of carbon dioxide produced (Appendix). We studied the relationship between the distance traveled and feedstock decomposition rate(see Figure 10). This analysis showed the greater the distance (which is also directly proportional to day traveled) greeted the decomposition % of feedstock.

The average assumed distance that the truck and train travel from the farm or the sugarcane industry to the PHA production plant is 500 Km. Keeping in mind this number we found that when we use trucks the CO2/kg PHA is greater than the normal truck. But there is one exception, that is above 27% degradation see Figure 4. Where there is a crossing between traditional and our method at 95 kg of CO2/Kg of PHA. Above this point the traditional method is not the best for transportation. This gives us an opportunity where our reactor can be used. On the other hand the analysis was also on placing reactors on trains that run on renewables. In the case of trains, the carbon emissions are advantageously low compared to traditional diesel transportation trucks and trains (see Figure5, Appendix (11,13,14)). Further the market for the 27% above is stated in the Market Analysis section of the report.

Since we save on carbon emission in both transportation and producing methane (captured during the process) it give a opportunity to tapinto the carbon credit market where we can earn around 0.2 to 20 dollars depending on the process (biogas-0.2 $, transportation- 5$, biomass-10$) the reactor is integrating(10). Which will allow us to save 67000$ for 50 trips (assuming 4.75 megatons of CO2 for 50 round trips using truck from plant to process plant) which otherwise could not have been a source of income and it allows for the decrease in cost of PHA sold and the end product, giving us a competitive advantage in the market. Extra calculation on frictional profits that can be made and carbon credit calculation is in the appendix.

Finally as the temperature of the planet continues to heat up. It will be difficult to use traditional methods to transport the feedstock(2). The conditions of storage will differ from region to region and our reactors will play an important role in combating the changing climate. As it allows no delay in the production process of PHA or any other fermentation process. Therefore our solution has variety of technical metrits form

4. Market Analysis

4.1. Fermenter market

The fermenters market was valued at USD 1.04 billion in 2017 and is projected to grow at a CAGR of 8.4% from 2018, to reach USD 1.69 billion by 2023.(1) The fed-batch fermenters dominated the market based on the process, because of the production of microbial cultures for various applications.

Increasing consumer preferences toward fermented products such as beer and cheese, and advancements in antibiotic technology are expected to drive the demand for fermenters in the global market.(3)

New technological innovations in fermenter design, coupled with the rising advancements in the bioplastic industry, such as the utilization of PHA and PBAT, will speed up the market growth in the coming years. PHAs are produced by a variety of microorganisms through bacterial fermentation of sugars or lipids(4). The culture of a microorganism, Cupriavidus necator, is placed in a medium and fed nutrients to synthesize PHA(5).

Key participants in the fermenters market are the fermenting equipment manufacturers, suppliers, and regulatory bodies. Asia Pacific is the fastest-growing market for fermenters in recent years. Emerging economies such as India have favorable market potential for fermented food products. The growing population is expected to drive the demand for fermented foods and beverages, which drive the demand for fermenters.(3)

4.2. PHA market

The PHA market increased from USD 80 million in 2022 to USD 93 million in 2023, and expected to reach USD 195 million by 2028 at a CAGR of 15.9%.(6) The key factor causing this growth is the limited use of non-degradable plastics, combined with the implementation of strict government regulations on the use of petroleum-based plastics. In this way, the green and environmentally friendly materials are rising in demand and have a stable growth.

The global demand for PHA is used for applications of packaging for food services, biomedical, and agriculture. Packaging contributes to 42% of the total global plastic waste generated and is the largest market for PHA. Europe has the largest market share for PHA market in 2022 based on European's environmental awareness and laws and regulations on biological waste treatment.(3)

Higher cost of PHA as compared to conventional polymers is a key restraint to the market's growth. The production of PHA has a cost of 20% to 80% higher than that of normal plastics because the polymerization process is more expensive since these bio-based manufacturing methods and materials are still in the early stages of development, and they still need to further work on the commercialization.(7)

Our solution allings with goal 12 of UN sustainable goals – Responsible Consumption And Production. Which allows us to market ourselves as an environment friendly and sustainable company which helps in receiving incentives form the Government.

4.3 Target Market

The Total Addressable market is the fermenter market, But there are 2 types of fermenters. One is the automatic and second is the semi automatic. Our offering is an automatic fermenter as it is easier to control and does not require human interference. Target market (automatic fermenter) is 50 million USD, this includes the locations that are far enough that 27% degradation of feed stock occurs as shown in Figure 4 and Figure 6 (9). This 50 million is derived from the overall market of the fermenter of 1.8 billion and targeting only the automatic fermenter.

5. Conclusion

By integrating fermentation processes directly within transportation infrastructure, stakeholders can reimagine transportation journeys as integral components of the production process. This approach not only streamlines logistics but also reduces transportation emissions, aligning with broader sustainability goals. And our product makes this possible.

Furthermore, the case of PHA production serves as a pertinent example of how innovative bioprocessing technologies can transform agricultural feedstock into sustainable products. As the planet warms up the problem of feedstock storage become harder and our process in integrating the reactors in production process, from PHA production to bio recycling in cities, Our reactors will play a crucial role in the production and the supply chain of various bioprocess allowing us to work towards achieving a more resilient and environmentally conscious future.

6. Reference

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7. Appendix

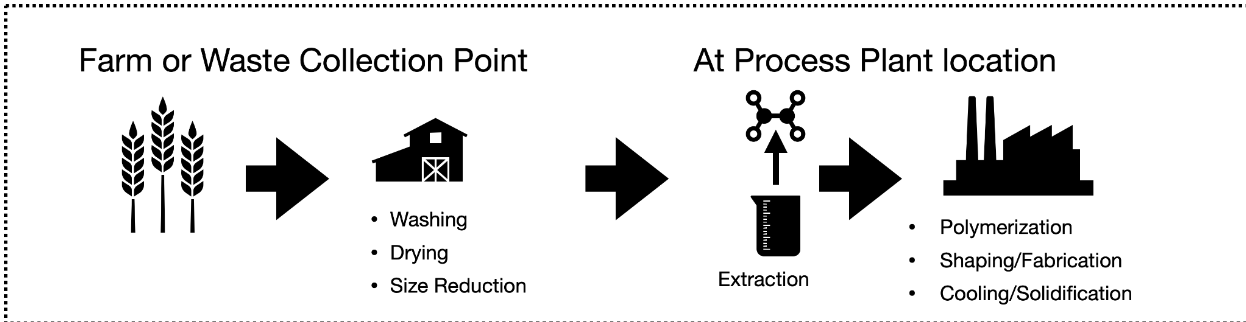

Figure 1 General overview of the process

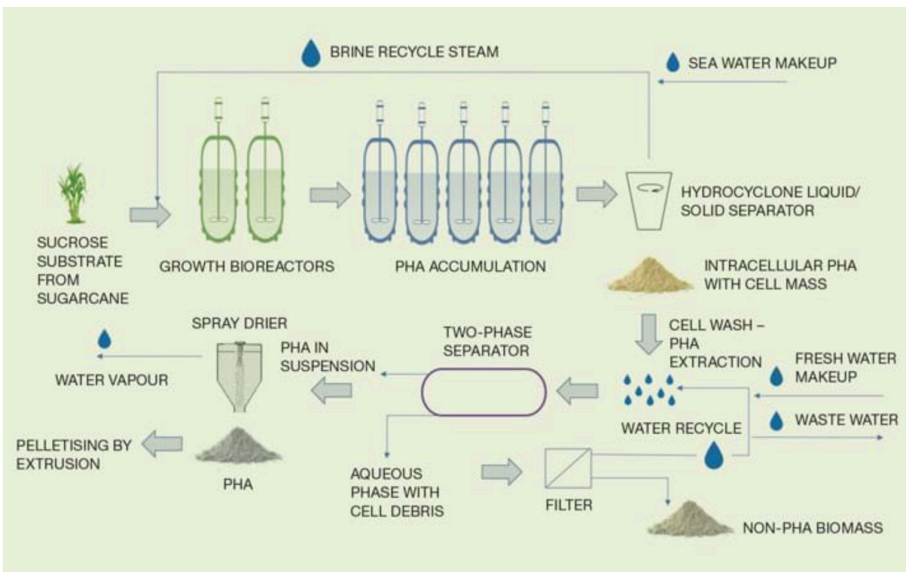

Figure 2 (at process plant location) [8]

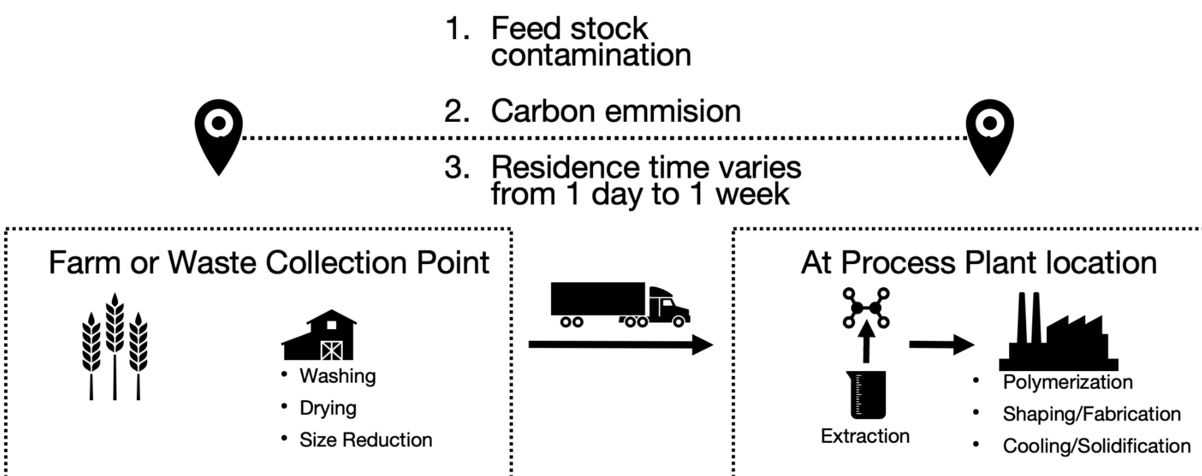

Figure 3 the problem

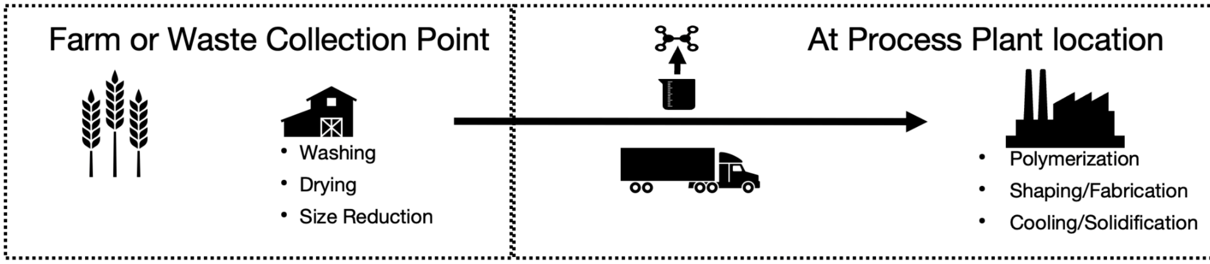

Figure 4 solution unify the transportation and fermentation process

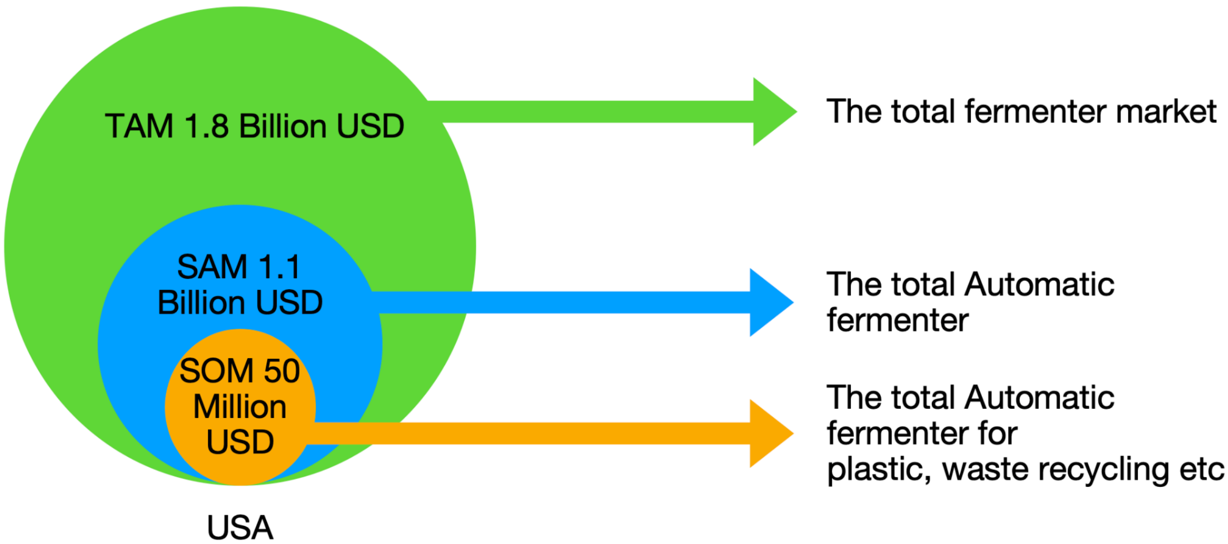

Figure 5 TAM, TSM, TOB

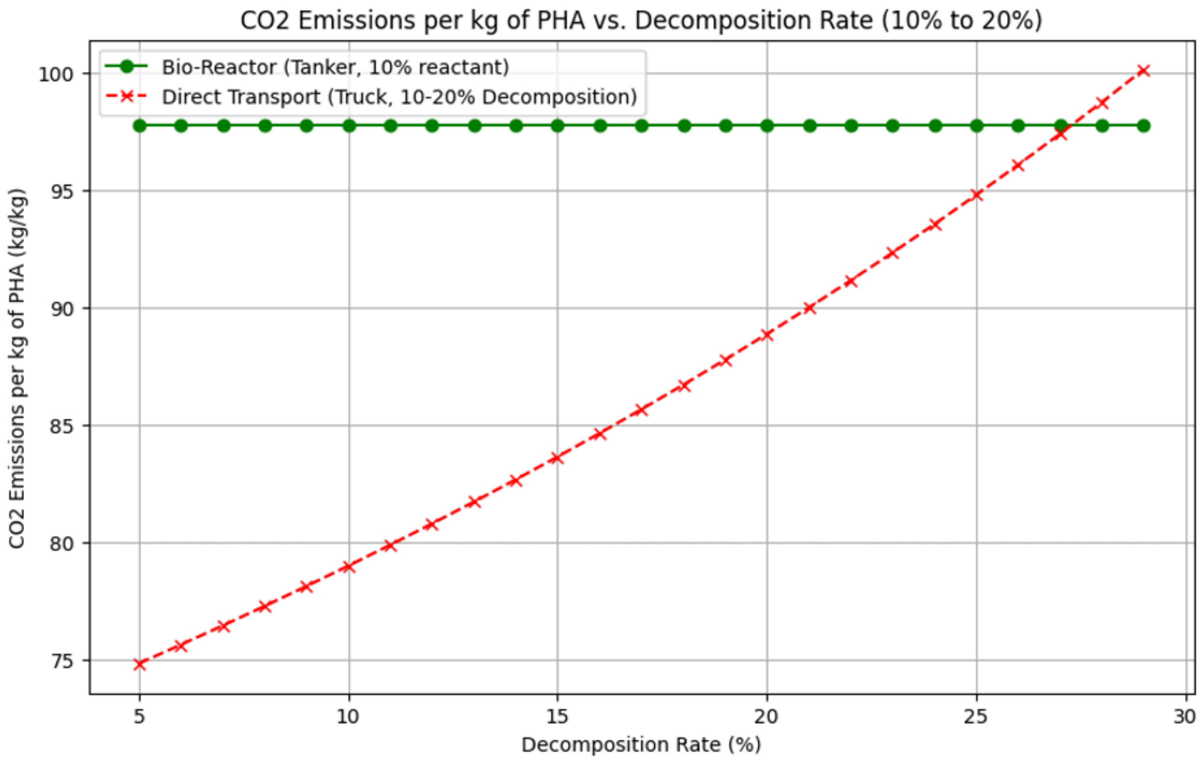

Figure 6 CO2 Emission per Kg of PHA vs. Decomposition Rate (10% to 20% max 30%)

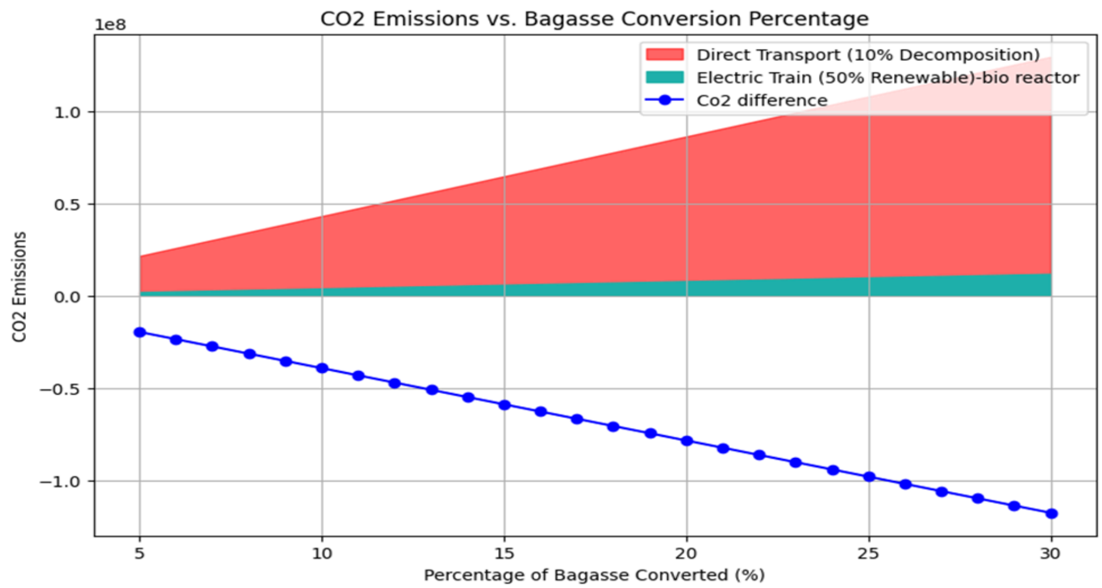

Figure 7 Comparison of train vs traditional Transport

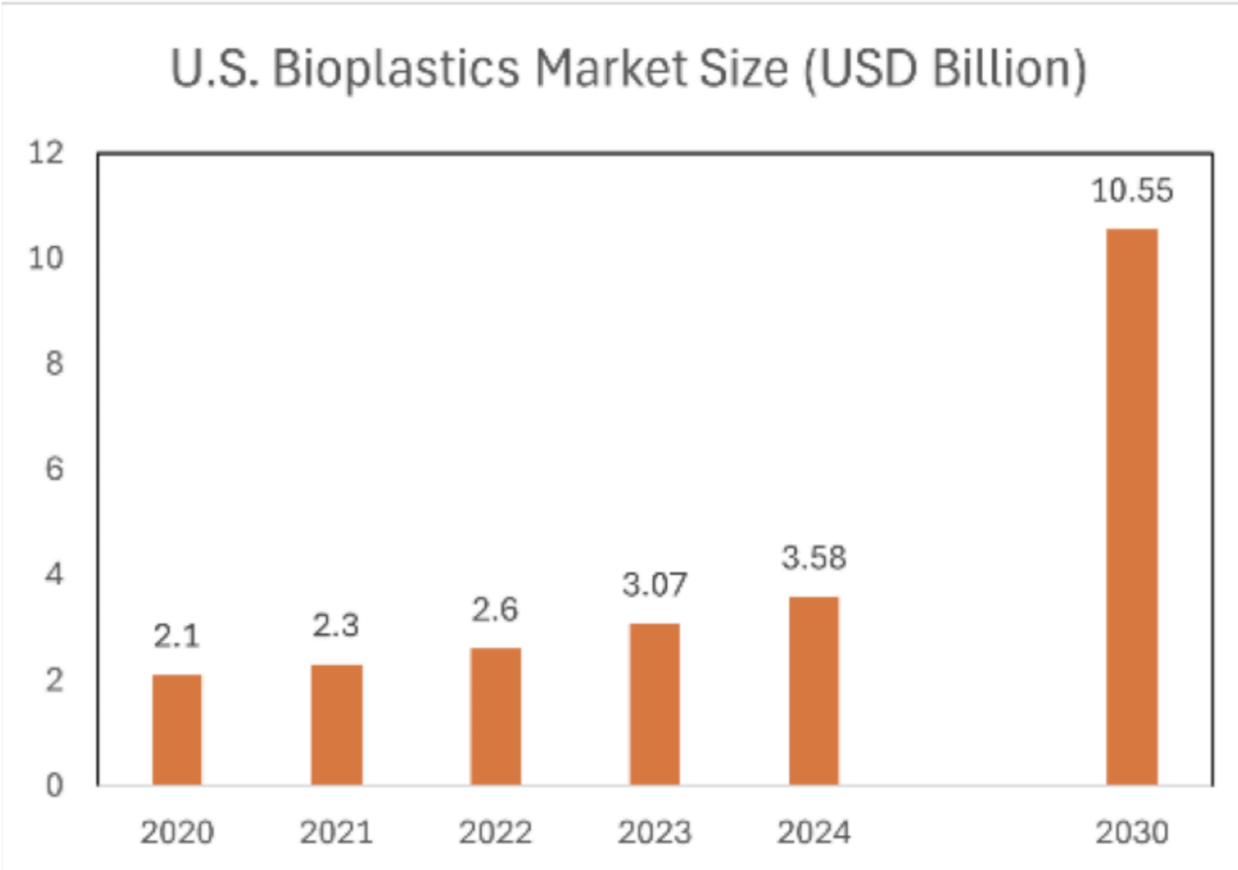

Figure 8 U.S. Bioplastics Market size

For Code please use the below link:
https://gist.github.com/harinagbandaru/d3ef86d42f6acd3128e377d580ff5f6f

FOR KOLHAPUR A DISTRICT CASE STUDY:

Daily Production Analysis

- Total Sugarcane Processed: 5.3 million tonnes
- Number of Mills: 48
- Number of Days: 61

Formula for Daily Production Per Mill:
Daily Production Per Mill=Total Sugarcane Processed/Number of Days×Number of Mills

=5,300,00061×48≈1810.109 tonnes/mill-dayDaily

Bagasse Production

- Bagasse Production Rate: 30%

Formula for Daily Bagasse Production Per Mill:
Daily Bagasse Production Per Mill=Daily Production Per Mill×Bagasse Production Rate

=1810.109×0.30≈543.033 tonnes/mill-day

Conversion to Glucose

- Conversion Efficiency to Glucose: 50%

Formula for Daily Glucose Production Per Mill:
Daily Glucose Production Per Mill=Daily Bagasse Production Per Mill×Conversion Efficiency

=543.033×0.50≈271.516 tonnes/mill-day

Formula for Glucose Losses:

Glucose Losses=Daily Bagasse Production Per Mill×Decomposition Rate×Number of Days×Cellulose Content×Conversion EfficiencyGlucose Losses

Conversion to PHA

- Conversion Efficiency to PHA: 30%

Formula for PHA Production from Glucose:
PHA Production=Glucose Production×PHA Conversion EfficiencyPHA Production=Glucose Production×PHA Conversion Efficiency

GlucoseLoss =Daily Bagasse Production per Mill×Decomposition Rate×Number of Days

×Cellulose Content×Conversion Efficiency

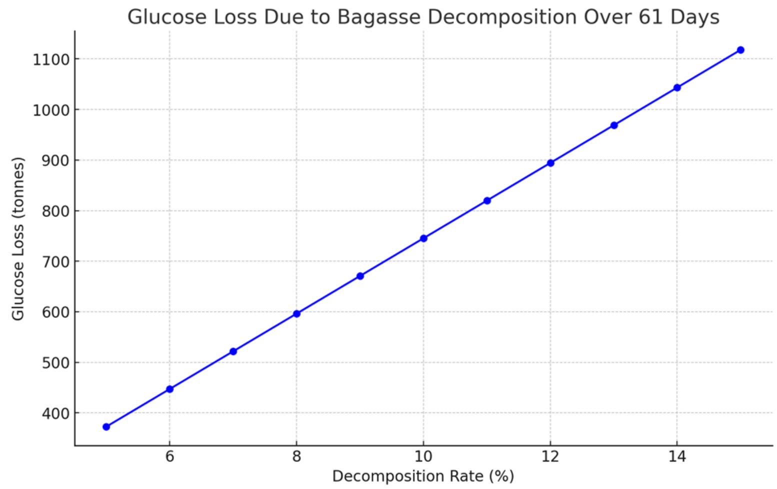

Figure 9 Glucose Loss Due to Bagasse Decomposition Over 61 Days

PHA Loss=Glucose Loss × PHA Conversion Efficiency

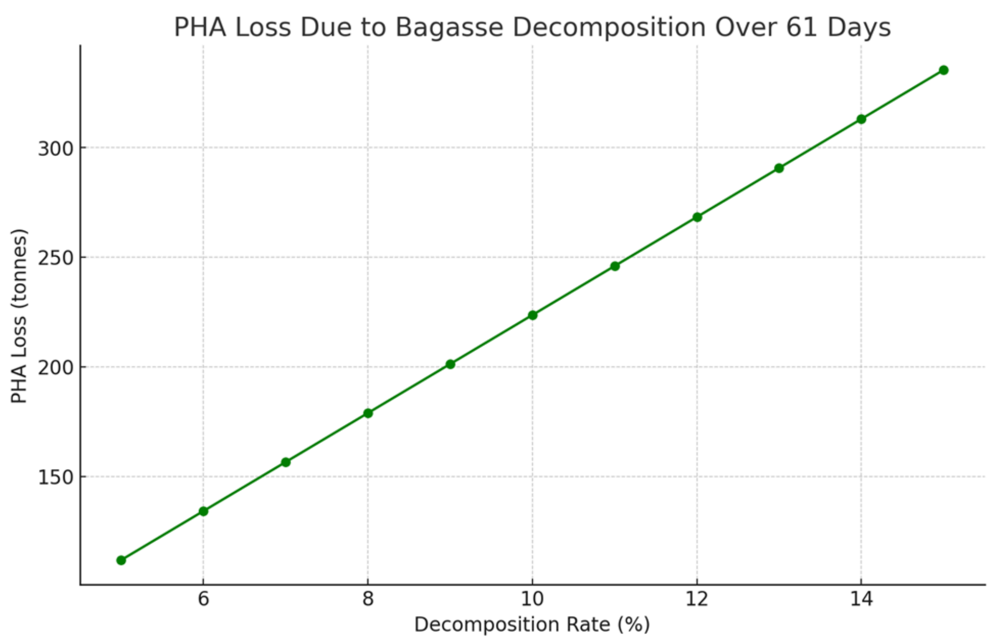

Figure 10 PHA Loss Due to Bagasse Decomposition Over 61 Days

IN INDIA

Total bagasse production: 90 million tonnes

Cellulose content in bagasse: 45%

Conversion efficiency of cellulose to glucose: 50%

Conversion efficiency of glucose to PHA: 30%

Decomposition rate = 5 to 15 %

Calculations:

1. **Total Glucose Production (No Decomposition):** The total glucose production is calculated by considering the full utilization of cellulose in bagasse without any losses due to decomposition:

   Total Glucose Production=Total Bagasse Production×Cellulose Content×Conversion Efficiency from Cellulose to Glucose

   Given the assumptions, the total glucose production is: Total Glucose Production=90,000,000 tonnes×0.45×0.50

2. **Total PHA Production (No Decomposition):** From the total glucose available, the amount of PHA produced is calculated by applying the glucose to PHA conversion efficiency: Total PHA Production=Total Glucose Production×Conversion Efficiency from Glucose to PHATotal PHA Production=Total Glucose Production×Conversion Efficiency from Glucose to PHA
3. **Impact of Decomposition on PHA Production:** To understand the impact of bagasse decomposition, we calculate the PHA production for varying decomposition rates ranging from 5% to 15%. The reduction in PHA production is directly proportional to the decomposition rate: Total PHA Production for Each Rate=Total PHA Production×(1−Decomposition Rate)Total PHA Production for Each Rate=Total PHA Production×(1−Decomposition Rate)

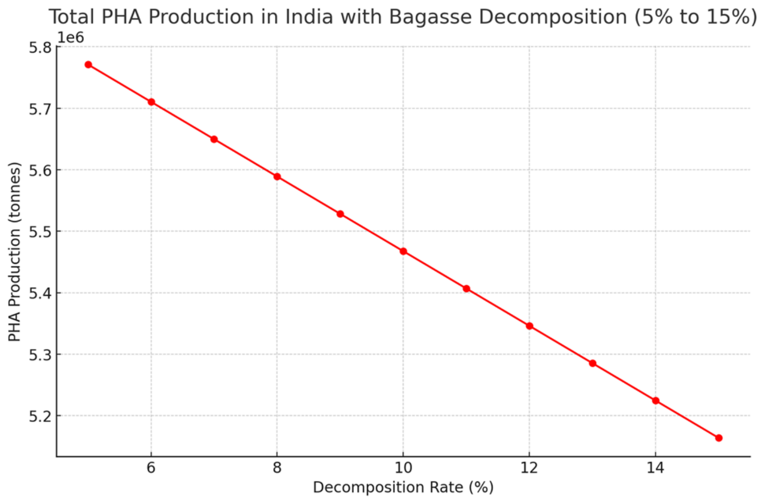

Figure 11 Total Production In India VS decomposition

Decomposition rate fixed at 8%

PHA Production=Total Bagasse Production×Percentage Utilized×(1−Decomposition Rate)×Cellulose Content×Conversion Efficiency from Cellulose to Glucose×Conversion Efficiency from Glucose to PHA

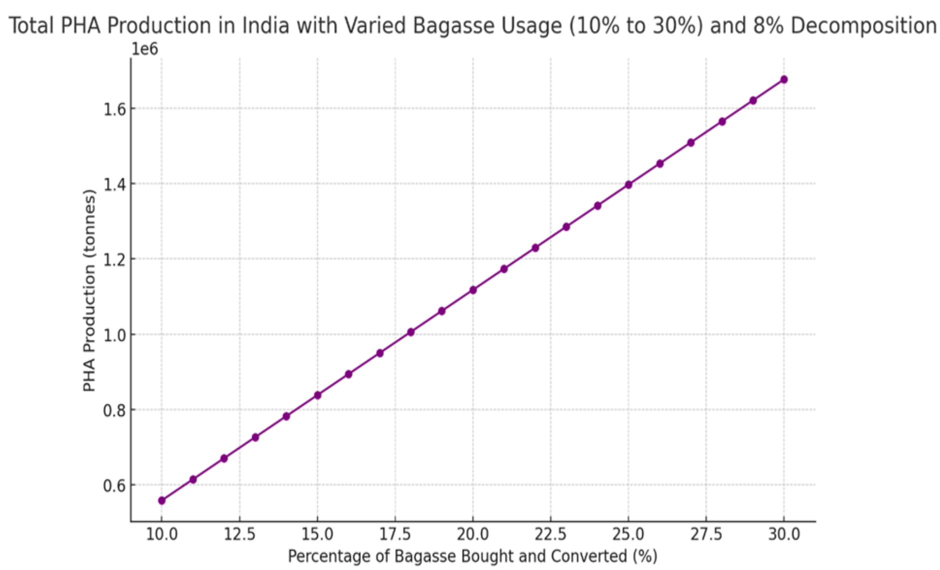

Figure 12 Total PHA Production In India Vs Varied Bagasse use with decomposition

The total PHA production is calculated for each percentage of utilized bagasse: PHA Production=Total Bagasse Production×Percentage Utilized×Cellulose Content×Conversion Efficiency from Cellulose to Glucose×Conversion Efficiency from Glucose to PHA

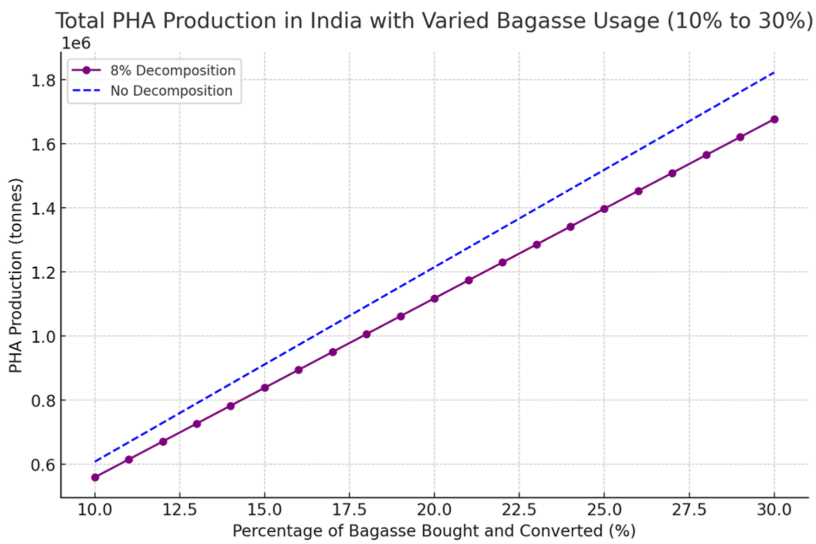

Figure 13 Total PHA Production In India Vs Varied Bagasse use

Parameters and Assumptions:

- **Total Bagasse Production:** 90 million tonnes annually.
- **Truck Load Capacity:** 25 tonnes per truck.
- **Round Trip Distance:** 1000 km.
- **Emission Factors:** 0.15 kg CO_2/km for tanker trucks and 0.12 kg CO_2/km for regular trucks.

Formulas Used:

1. **Bio-Reactor Transportation:** The amount of bagasse transported to the bio-reactor includes the weight of any byproducts (assumed as a percentage increase over the raw bagasse weight)

   Total Truck Trips for BioReactor=Effective Bagasse Used for BioReactor×(1+Byproduct Weight Percentage)/Truck Load Capacity

   Total CO2 Emission for BioReactor=Total Truck Trips for BioReactor×Round Trip Distance×Emission Factor for Tanker

2. **Direct Transport:** Total Truck Trips for Direct Transport=Effective Bagasse Used for Direct TransportTruck Load Capacity/Total Truck Trips

Total CO2 Emission for Direct Transport=Total Truck Trips for Direct Transport × Round Trip Distance × Emission Factor for Truck

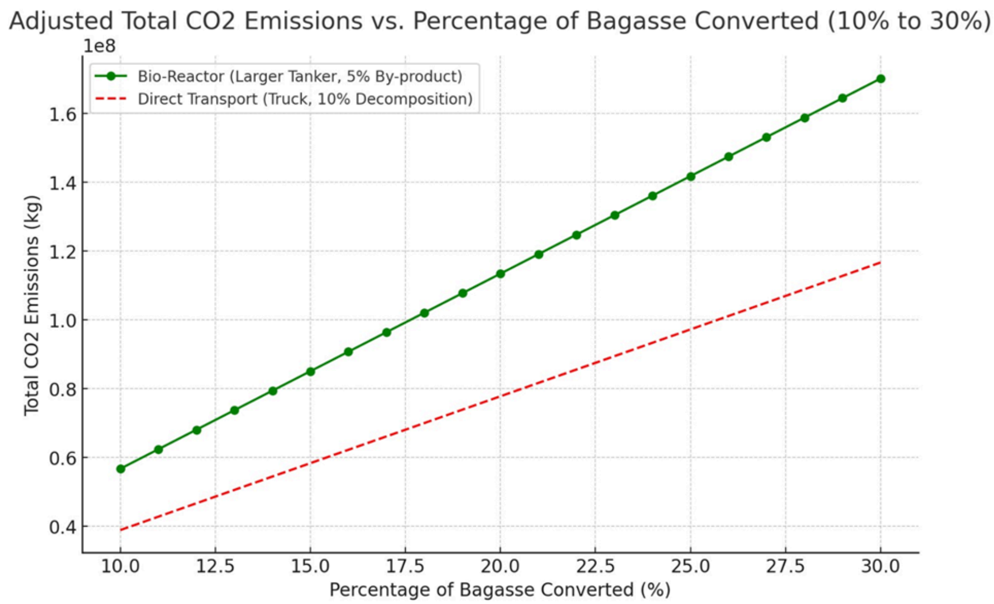

Figure 14 Total CO2 emission Vs % Bagasse Converted

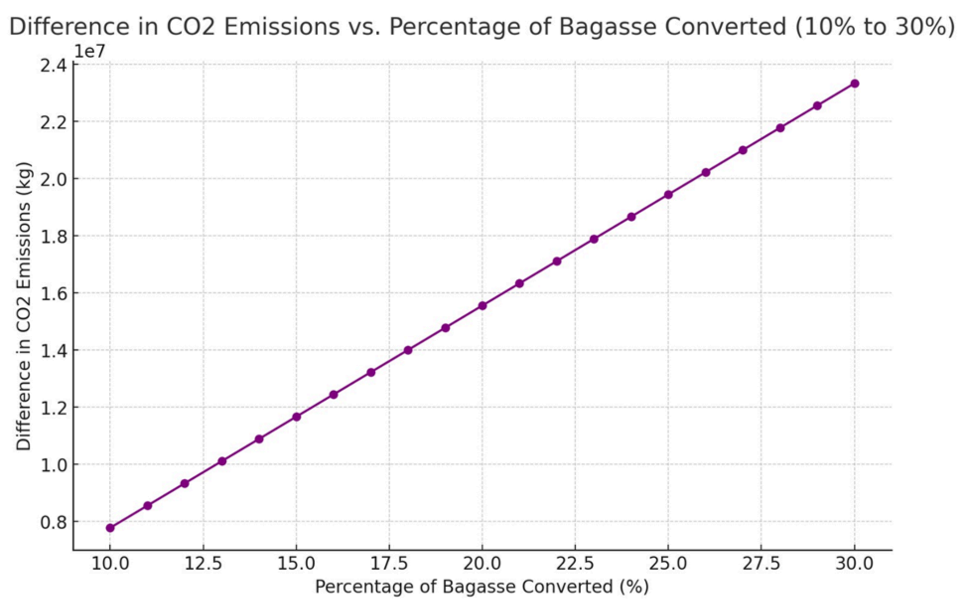

Figure 15 difference in CO2 emission Vs % Bagasse Converted

Parameters and Assumptions:

- **Total Bagasse Production:** 90 million tonnes annually.
- **Truck Load Capacity:** 25 tonnes per truck.
- **Round Trip Distance:** 1000 km.
- **Emission Factors:** 0.12 kg CO2/km for trucks and 0.02 kg*(1-x) CO2/km for regular trains. where x is percentage from green renewable sources here it is 50%

Formulas Used:

1. **Bio-Reactor Transportation:** The amount of bagasse transported to the bio-reactor includes the weight of any byproducts (assumed as a percentage increase over the raw bagasse weight)

   Total Train Trips for BioReactor=Effective Bagasse Used for BioReactor×(1+Byproduct Weight Percentage)/Train Load Capacity

   Total CO2 Emission for BioReactor=Total Train Trips for BioReactor×Round Trip Distance×Emission Factor for Train

2. **Direct Transport:** Total Truck Trips for Direct Transport=Effective Bagasse Used for Direct TransportTruck Load Capacity/Total Truck Trips

   Total CO2 Emission for Direct Transport=Total Truck Trips for Direct Transport × Round Trip Distance × Emission Factor for Truck

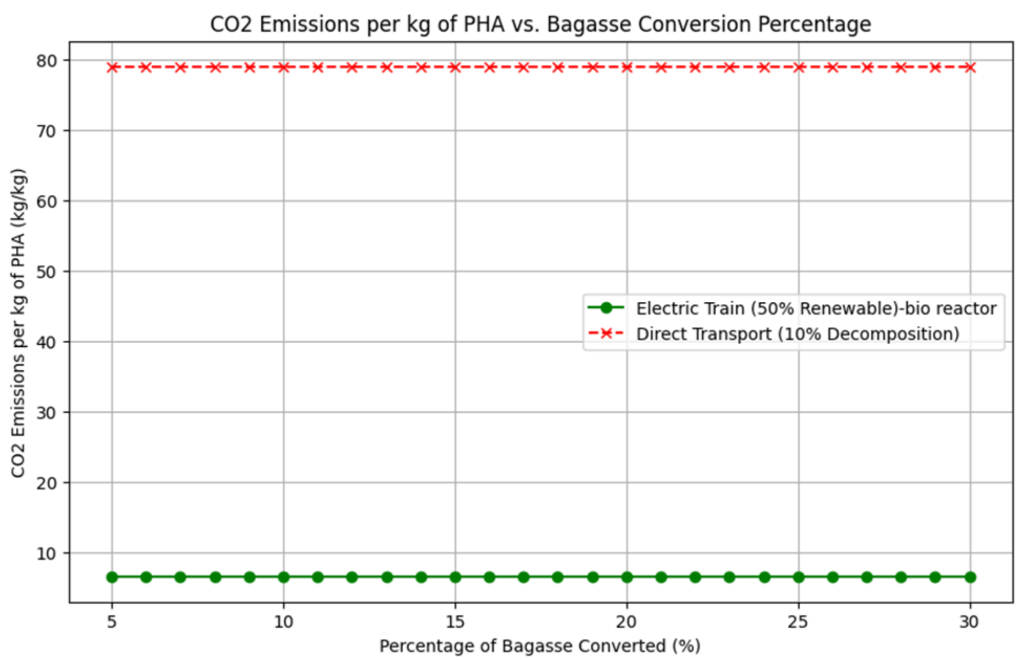

Figure 16 CO2 emission using train

For 15 % baggage conversion

1. **Calculate CO2 Savings:**
   - CO2 savings = Emissions from Direct Transport - Emissions from Electric Train
   - CO2 savings = 250,000 tonnes - 50,000 tonnes = 200,000 tonnes
2. **Carbon Credits Calculation:**
   - Each tonne of CO2 savings translates directly to one carbon credit.
   - Total carbon credits = 200,000 credits

3. Total Cost/Revenue from Carbon Credits:

   - Total cost/revenue = Number of carbon credits * Price per carbon credit
   - Total cost/revenue = 200,000 credits * $5/credit = $1,000,000

1. **Effective Bagasse**:

Effective Bagasse=90,000,000 tonnes×0.15×(1−0.08)=12,420,000 tonnes

2. **PHA Yield Calculation**:

PHA Yield=12,420,000 tonnes×0.45×0.50×0.30=837,150 tonnes of PHA

3. **Cost Calculation**:

Total Cost=(12,420,000 tonnes×$230)=$2,856,600,000

4. **Cost Per kg of PHA**:

Cost per kg of PHA=$2,856,600,000/837,150,000 kg≈$3.41 per

Effective Bagasse:

Effective Bagasse=90,000,000 tonnes×0.15=13,500,000

PHA Yield Calculation:

PHA Yield=13,500,000 tonnes×0.45×0.50×0.30=911,250 tonnes

Cost Calculation:

Total Cost=(13,500,000 tonnes×$180)=$2,430,000,000

Cost Per kg of PHA:

Cost per kg of PHA=$2,430,000,000/911,250,000 kg≈$2.66 per kg

Revenue from PHA Sales:

1. **Revenue with 8% Decomposition:**
   - PHA Production: 837,150 tonnes or 837,150,000 kg
   - Revenue = 837,150,000 kg × $5.00/kg = $4,185,750,000
2. **Revenue with No Decomposition:**
   - PHA Production: 911,250 tonnes or 911,250,000 kg
   - Revenue = 911,250,000 kg × $5.00/kg = $4,556,250,000

Production Costs:

- **Cost with 8% Decomposition:** $2,856,600,000
- **Cost with No Decomposition:** $2,430,000,000

Net Revenue from PHA Sales:

1. **Net Revenue with 8% Decomposition:**
   - Net Revenue = $4,185,750,000 - $2,856,600,000 = $1,329,150,000
2. **Net Revenue with No Decomposition:**
   - Net Revenue = $4,556,250,000 - $2,430,000,000 = $2,126,250,000
1. **Net Revenue with 8% Decomposition (previously calculated):**
   - Revenue from PHA sales = $4,185,750,000
   - Production Costs = $2,856,600,000
   - Net Revenue = $1,329,150,000
   - **Subtract Cost of Carbon Credits:** $1,329,150,000 - $26,640,000 = $1,302,510,000
2. **Net Revenue with No Decomposition (previously calculated):**
   - Revenue from PHA sales = $4,556,250,000
   - Production Costs = $2,430,000,000
   - Net Revenue = $2,126,250,000
   - **Subtract Cost of Carbon Credits:** $2,126,250,000 - $26,640,000 = $2,099,610,000

Summary of Adjusted Total Profits:

1. **Total Profit with 8% Decomposition:**
   - $1,302,510,000
2. **Total Profit with No Decomposition:**
   - $2,099,610,000

Profit increase = $797,100,000