Spring 5-9-2021

Exploration of the Sludge Biodiesel Pathway

Zachary Christman

Exploration of the Sludge Biodiesel Pathway

Zachary Christman

Abstract

Wastewater sludge is an overlooked source of fat, oil, and grease (FOG) that could be converted into biodiesel. The United States produces about 8 million tons of sludge per year. The disposal cost for this amount of sludge is about 2 billion dollars. The widespread availability and low cost of sludge compared to other biodiesel raw materials make it an economical choice for a renewable fuel. Using sludge as a raw material can produce 25 to 30 mg per gram of fatty acid methyl ester (FAME); the main component of biodiesel. Sludge biodiesel has the potential of transforming a portion of the waste that is normally landfilled, incinerated or anaerobically digested into a high energy liquid fuel.

Introduction

Biomass is a broad classification for any fuel such as energy crops, agricultural residue, municipal waste, and some types of industrial byproducts. Biomass has several advantages over petroleum based fuels: [3]

- Large availability worldwide
- Improved waste management practices
- Potential to be produced and consumed in a carbon neutral system

Biomass can be organized in two different ways. The energy or fuel producing plant is located nearby the biomass source with the product shipped or transmitted from there. The second method is to have a large central processing plant where biomass sources are transported for conversion into the final product. A central processing plant usually has multiple sources of raw materials. [3]

A biomass supply chain is usually composed of these five system components: [3]

- Biomass harvesting / collection from one or more raw material suppliers.
- Pretreatment or extraction of materials needed for the biomass system
- Storage in one or multiple locations
- Transportation of raw materials and final products
- Energy conversion and use

This article will focus on a type of biomass called wastewater treatment plant (WWTP) sludge. Wastewater is any material suspended or dissolved in water that needs to be treated to reduce environmental damage and health concerns. Wastewater can include anything from dairy and distillery byproducts to sewage. [3]

A WWTP applies microbiological processes to treat domestic, commercial, and industrial wastewater. The material that is generated by this process is a semi-solid material with a high level of organic matter. Primary sludge has a significant level of fat, oil, and grease (FOG) that comes from industrial and commercial wastewater sources. Secondary sludge is extracted in the secondary treatment tank after primary sludge has been removed. Secondary sludge also known as activated sludge has FOG that is generated by bacteria and other organisms that have grown on the nutrients present in wastewater sources. [5]

The United States produces about 8 million tons of sludge per year. The disposal cost for this amount of sludge is about 2 billion dollars a year. Common forms of sludge management are landfilling, incineration and anerobic digestion. This article is designed to guide the reader through the process of sludge biodiesel. The sludge biodiesel process allows for a portion of this material to be converted into a high energy liquid fuel. This exploration begins at the wastewater treatment plant and ends at the biodiesel plant with the final product. Biodiesel is composed of fatty acid methyl esters (FAMEs) that are formed by the transesterification of a FOG material with methanol. [5]

Dewatering and Drying

Dewatering is the first step in wastewater sludge management. This process is to reduce the amount of water within the sludge so that the drying step is more economical. The most common method of mechanical dewatering is done using filtration, compression, or centrifugation. [1]

Before transportation of the sludge to a biodiesel plant the material must be dried. The drying process has these purposes: [1]

- Reduces the volume of the sludge improving storage
- Decreases the cost of transportation and handling
- Increases the caloric value of the sludge

Table 1. The advantages and disadvantages of different drying technologies.[1]

Used technique	Advantages	Disadvantages
Convective drying	• Design allowing easy manipulation • Dried product used in agriculture	• Relatively long drying time • Bad odours • Gaseous emissions
Conductive drying	• No pollution of the heat carrying medium • Steam and odor confinement • VOC concentration is low • Reduction of fire and explosion risks • Dried product used in industrial applications	• Relatively long drying time • Sticky phase alters dryer performances
Superheated steam drying	• No dust • No volatile emission • Pathogen free sludge • Short drying time • Low energy consumption	• High temperatures are needed

The two main types of drying are convective and conductive. The convective dryer uses hot air or steam that goes through the product causing water to evaporate. To increase the evaporation, rate the surface area should be maximized through extrusion or granulation. The most common industrial convective dryers are belt dryers, flash dryers, fluidized bed dryers and rotary dryers. Cross sections of these types can be seen in figure 1 below. [1]

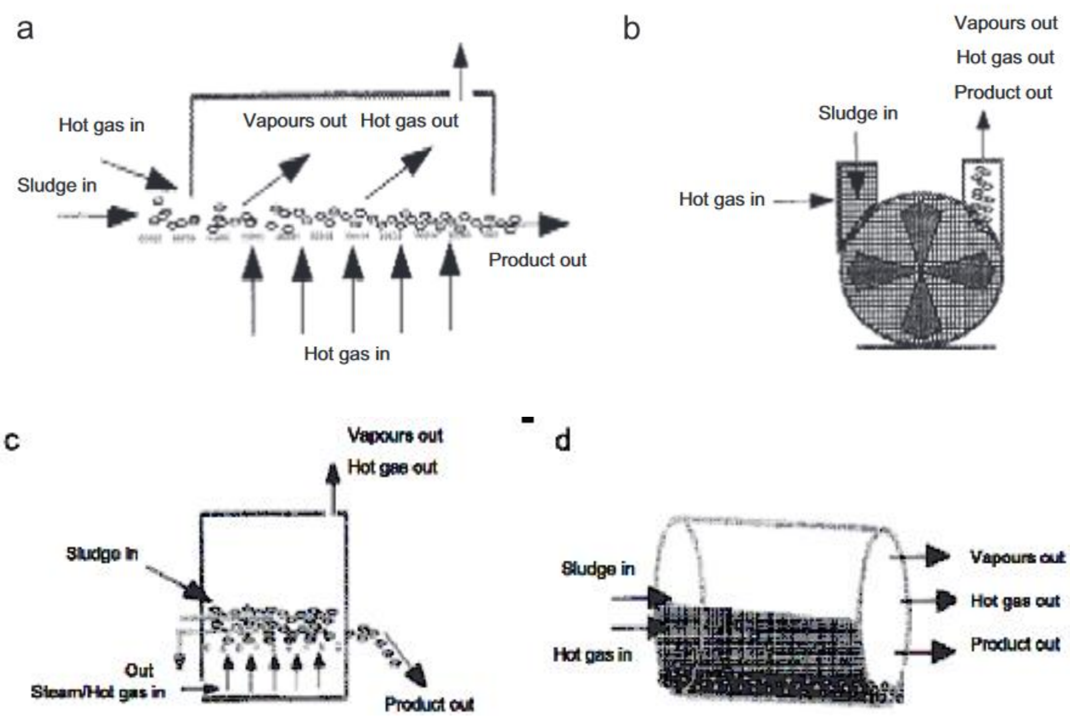

Figure 1. Cross sections of 4 different types of convection dryers.
a) belt dryer b) flash dryer
c) fluidized bed d) Rotary Dryer. [1]

Conductive drying works by heating a surface to indirectly heat the sludge. Generally thermal oil or saturated steam at 0.85 MPa is used as the heating fluid. In conductive drying large agitators stir the sludge past the drying surface for equal heating. Two types of conductive dryers can be seen in Figure 2.[1]

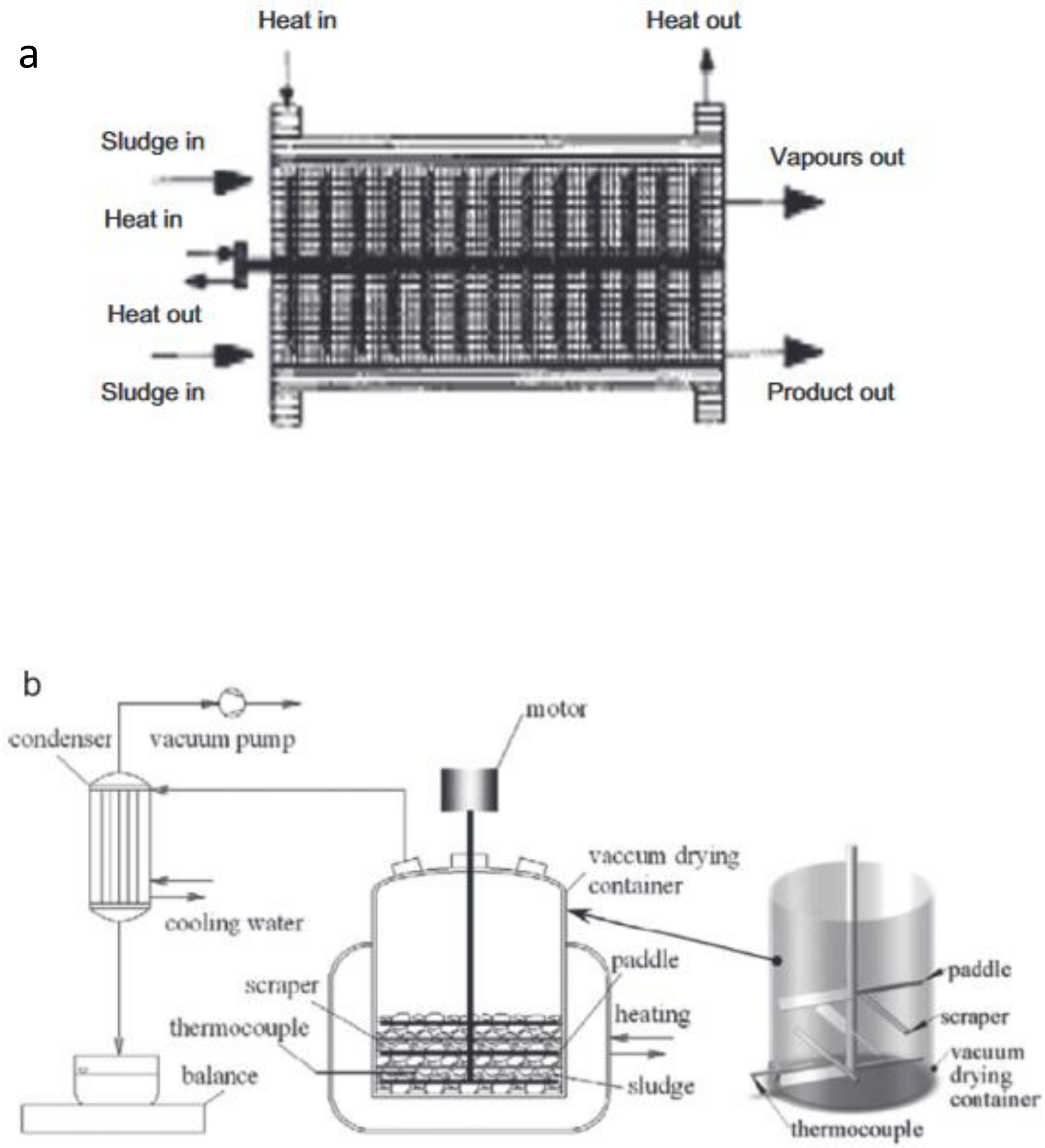

Figure 2. Different types of conductive dryers. a) disc dryer b) paddle dryer.

Pipeline transport of sludge

The use of pipelines to transport sludge depends on a variety of factors such as: [6]

- Density
- pH of the sludge
- Viscosity
- Total solids (TS)
- Cost of inlet and outlet stations
- Cost of sludge storage
- Building and foundation
- Fitting and valves
- Pumping cost
- Road access
- Pipeline construction
- Operating cost
- Pump booster station cost

Wastewater sludge has a pH of about 7.0, therefore inexpensive materials such as PVC can be used. Another factor about sludge is that it has a high level of viscosity. This requires pumps that can exert a high level of pressure to force the material down the pipeline without clogging. The pumps and electricity needed to transport the sludge increases the cost of the building project. Storage of the sludge at a wastewater treatment plant may be used to optimize the performance and use of the pipeline. Pipeline material and insulation cost is 62% of the total construction price. Pipelines have the advantage of lower noise levels than truck transport. [6]

Truck transport of sludge

For trucks with a load capacity of 30 m^3 and a tandem trailer truck of 40 m^3 the economic factors of note are: [6]

- Independent license fees
- Insurance fees
- Travel distance
- Product weight
- Product characteristics (for example: liquid or solid)
- Management and administrative help
- Truck ownership
- Truck fuel cost
- Labor cost

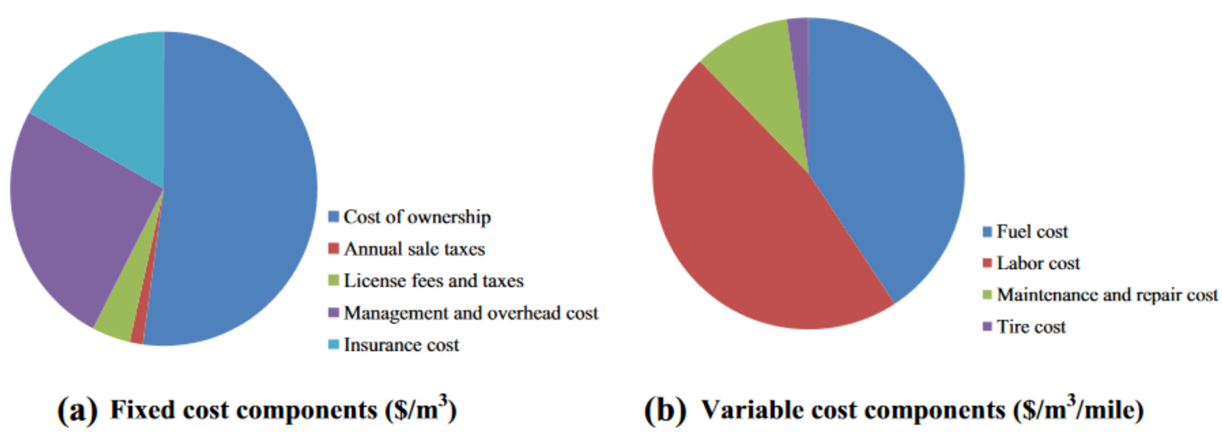

Figure 3. Distribution of wastewater treatment sludge transportation costs for single trailer trucks with a load capacity of 30 m^3 [6]

Table 2. Total transportation cost per gallon of biodiesel versus volume transported [6]

Mode	Volume Shipped (m^3/day)					
	150	250	350	480	700	1000
	$ amount per gallon of biodiesel					
Single trailer (own)	0.101	0.103	0.103	0.101	0.103	0.103
Single trailer (rent)	0.131	0.131	0.133	0.131	0.133	0.133
Tandem trailer (own)	0.098	0.098	0.098	0.096	0.098	0.096
Tandem trailer (rent)	0.125	0.125	0.125	0.123	0.125	0.123
Pipeline	0.152	0.109	0.089	0.073	0.058	0.047

Table 3 Transportation cost per gallon of biofuel as a function of distance traveled. [6]

Mode	Distance (miles)							
	25	50	75	100	125	150	175	200
	$ amount per gallon of biofuel							
Corn stover – Ethanol[a]	0.052	0.079	0.105	0.131	0.159	0.186	0.213	0.240
Sludge – Biodiesel (owned TT truck)	0.077	0.096	0.114	0.133	0.152	0.171	0.191	0.208
Sludge – Biodiesel (pipeline) [b]	0.077	0.152	0.226	0.301	0.375	0.449	0.524	0.598
Sludge – Biodiesel (pipeline) [c]	0.037	0.073	0.109	0.144	0.180	0.216	0.251	0.287
Sludge – Biodiesel (pipeline) [d]	0.024	0.047	0.070	0.093	0.115	0.138	0.161	0.184

[a] The distance fixed and variable parameters for truck transportation come from Mahmudi and Flynn (2006). The conversion rate for corn stover comes from Ekşioğlu et al. (2009).
[b] Calculated based on pipeline capacity of 150 m^3/day.
[c] Calculated based on pipeline capacity of 480 m^3/day.
[d] Calculated based on pipeline capacity of 1000 m^3/day.

In-situ Biodiesel Production From Secondary Sludge Method

Developer: Xia Chi et al.

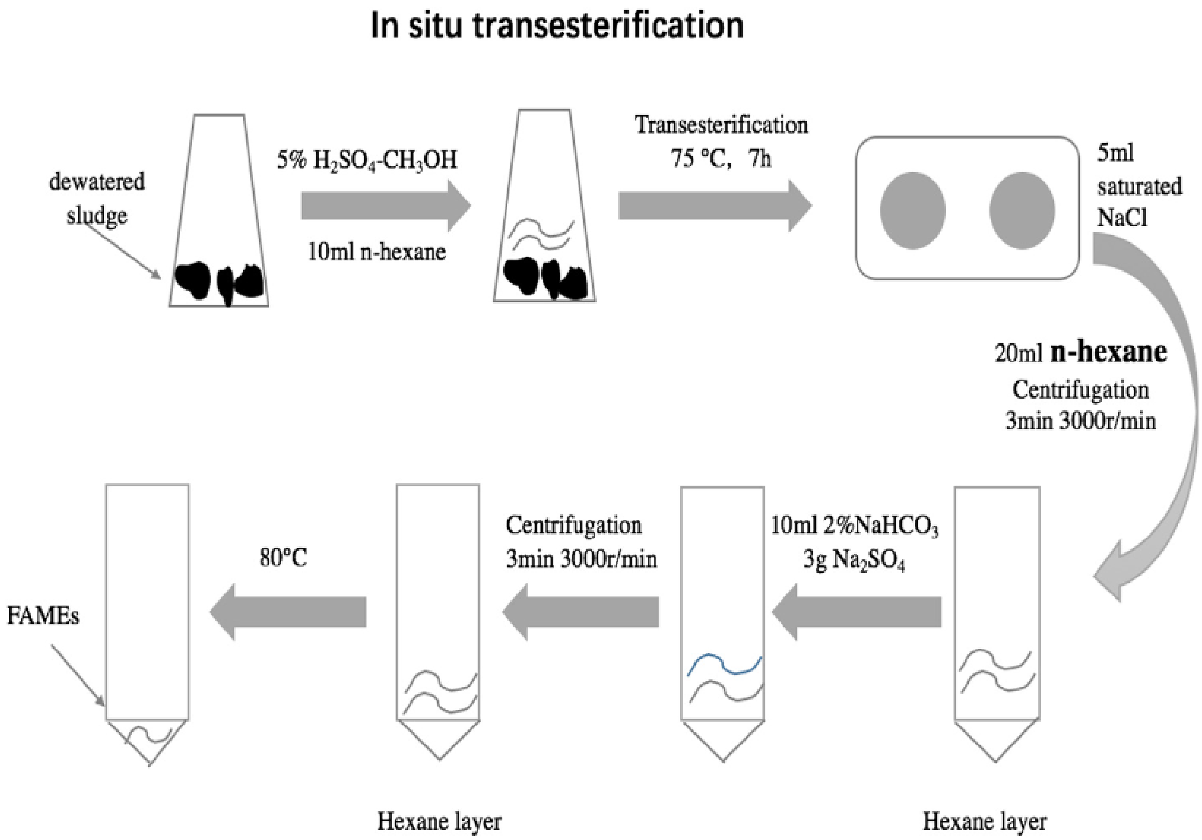

Figure 4. Biodiesel production process for secondary sludge[2]

As can be seen in the above Figure 4, the steps for the Xia Chi et al. in-situ biodiesel production from secondary sludge can be followed step by step below. [2]

With the addition of n-hexane to the reaction mixture the amount of biodiesel produced increased from 2.18 +/- 0.58 mg/g to 15.44 +/- 3.74 mg/g. The n-hexane improves the extraction of the FOG material from the secondary sludge during processing. Also, n-hexane improves the reaction because FOG has a low level of solubility with methanol. [2]

1. Secondary sludge (13 to 16% solids) from a wastewater treatment plant in Beijing was collected.

2. Belt press drying of sludge. 1 gram of sludge is added to the chamber.

3. Add 7.5 ml of 5% sulfuric acid and methanol with 10 ml of n-hexane

4. The chamber is placed into a water bath at 75 degrees Celsius for 7 hours.

5. The n-hexane and methanol vapor were condensed and returned to the chamber.

6. After cooling the chamber to room temperature, 5ml of saturated salt solution was added.

7. The mixture was extracted 3 times with n-hexane.

8. The extracted solution was centrifuged at 3,000 RPM for 3 minutes.

9. The n-hexane layer was collected from the solution.

10. 10ml of 2% (w/v) sodium bicarbonate and 3 grams of anhydrous sodium sulfate was added and centrifuged.

11. The upper n-hexane layer was removed from the solution.

12. The n-hexane was evaporated at 80 degrees Celsius to obtain biodiesel

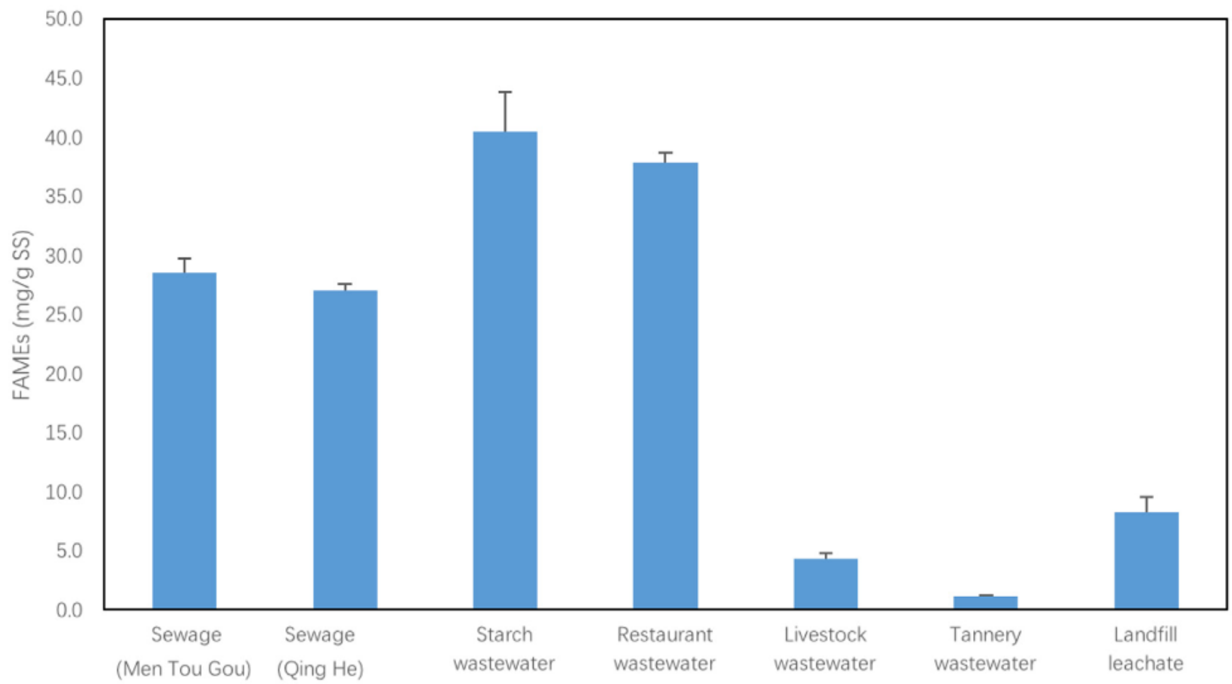

Figure 5 Biodiesel production from seven different wastewater sources. [2]

Conclusion

The fat, oil, and grease (FOG) contained within wastewater treatment plant sludge is a valuable resource for biodiesel production. The level of fatty acid methyl esters (FAME) produced depends on the source of the wastewater. Secondary sludge has more microbial FOG when it comes from a restaurant or industry wastewater with a high level of carbohydrates such as starch. The microbes are fed more energy rich materials from these sources, therefore more oil is produced that can be turned into biodiesel. Sludge is available in large quantities throughout the year and is a low-cost source of oily material. In this article a brief overview of drying technology was presented, followed by the economic factors of transporting dried sludge to the biodiesel plant. The method of biodiesel production highlighted in this article is in-situ transesterification. This method was chosen as the most likely approaches to scale up for a sludge biodiesel pilot plant.

References

1. Bennamoun, Lyes, Patricia Arlabosse, and Angélique Léonard. "Review on fundamental aspect of application of drying process to wastewater sludge." Renewable and Sustainable Energy Reviews 28 (2013): 29-43.

2. Chi, Xia, et al. "Influent characteristics affect biodiesel production from waste sludge in biological wastewater treatment systems." International Biodeterioration & Biodegradation 132 (2018): 226-235.

3. Iakovou, E., et al. "Waste biomass-to-energy supply chain management: a critical synthesis." Waste management 30.10 (2010): 1860-1870.

4. Kwon, Eilhann E., et al. "Biodiesel production from sewage sludge: new paradigm for mining energy from municipal hazardous material." Environmental science & technology 46.18 (2012): 10222-10228.

5. Marufuzzaman, Mohammad, Sandra Duni Ekşioğlu, and Rafael Hernandez. "Environmentally friendly supply chain planning and design for biodiesel production via wastewater sludge." Transportation Science 48.4 (2014): 555-574.

6. Marufuzzaman, Mohammad, Sandra D. Ekşioğlu, and Rafael Hernandez. "Truck versus pipeline transportation cost analysis of wastewater sludge." Transportation Research Part A: Policy and Practice 74 (2015): 14-30.