Student Handout

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Scenario

As she entered the elevator from the parking garage, Janine recognized that vaguely familiar feeling of excitement and nervousness in her stomach. She got off on the third floor and was immediately transported back to her first day of high school: new smells, new people, and new opportunities.

Just a month prior, Janine graduated from college, and today was her first day of work as an analyst for Energy Associates, Inc., a consulting firm in Washington, D.C., that specializes in renewable energy solutions. She made her way to her cubicle, got settled, and then her boss Martha called her in for her first official meeting.

Pen and pad in hand, Janine entered Martha's office.

Martha closed the door and immediately asked, "So, Janine, what do you know about renewable energy?"

Having just graduated with a degree in environmental engineering, Janine had her bases covered. She began, "Well, there are a number of possible sources: hydro, solar, wind, geothermal, tidal, and biofuels. Is there one in particular you'd like to discuss?"

"Aren't you forgetting about one?" Martha asked.

"I don't think so…"

Martha went on, "What if I told you there was another renewable energy source with none of the intermittency problems of wind or solar and capacity factors that rival those of coal plants? Beyond that, the fuel source is abundant and free."

Janine laughed nervously. "This must be a thought exercise to test my ability to think on my feet," she thought. At that moment, Martha tossed a large file folder on the desk labeled "Wastewater-to-Energy."

"This is your first project. We're pitching to a new client in two weeks—D.C. Water and Sewer Authority—and we need to propose a system to use their wastewater to produce energy. We need to account for *everything*: engineering constraints, investment costs and potential revenue, political concerns, environmental credits, CO2e emissions, you name it! This is a huge project, and if our company wins the bid, you can rest assured you'll have a job here for at least the next two years. So get to work. My door is always open if you have any questions."

Janine went back to her desk, glanced down at her coffee, and then opened the folder.

Procedure

Step 1: Proposing a solid management processes based on individual factors

1. Gather important information on the four possible types of solid management processes by reading the provided information sheets on each management system with your team.
2. In combination with the pre-reading, consider the types of information that you will use for prioritizing solid management processes. There are two overarching factors. You will examine each factor individually according to the order assigned to your team by the instructor.
3. For each factor, read the provided information and discuss a strategy for incorporating it into your decision framework with your team.
4. Prioritize the solid management processes base on the information provided. Develop a detailed and justifiable strategy for incorporating the information. Write down your team's proposed solution.
5. Present your recommendation with your team's rationale. Avoid generalities and anecdotal arguments--as a consultant you must provide a data-driven solution to this problem!

Step 2: Develop a final recommendation based on all the factors

1. Synthesis all of your information based on the two factors.
2. You may think about other factors and combine them into your team's final proposed solution. However, you should provide a detailed explanation of your team's rationale and any supporting information.
3. Write a brief report summarizing your method of synthesis and reasons for your recommendation.

Step 3: Present your team's proposed solution

Your presentation should include your team's final recommendation, the method that you used to synthesize information across factors, reasons why you proposed this solution, problems that made it hard to develop a final recommendation, and any additional information that would have helped you in designing a solution.

SOLID END PRODUCT MANAGEMENT OPTIONS

About one ton of solid end product is produced from one million gallons of wastewater that is passed through a wastewater treatment process.

1. Land application

Source: http://www.appleton.org/departments/page_f93a1877928c/?department=b69309298e6b&subdepartment=6a0e8b8ac166

Land application is a process to spread or spray biosolids on an agricultural land surface, forestland and/or mining site. However, solid end products from a wastewater treatment plant (WWTP) have to be treated to meet all regulatory[1] requirements, which is standard for the use and disposal of sewage sludge 40 CFR 503 (US. EPA, 1993).

Solid end products from a WWTP can therefore be used directly to produce Class B biosolids through a lime stabilization process.

[1] http://yosemite.epa.gov/r10/water.nsf/NPDES%2BPermits/Sewage%2BS825/$FILE/503-032007.pdf

SOLID END PRODUCT MANAGEMENT OPTIONS

2. High-end fertilizer

Source: http://envstudies.brown.edu/research/LULCC/research/brazil.html

Fertilizer can be categorized into two groups based on its composition:

1. Inorganic fertilizer
2. Organic fertilizer.

Solid end products from a WWTP can be composted, which kills pathogens, reduces odor, and produces a stable and marketable product. They can therefore be used directly to produce Class A fertilizer through a composting process.

SOLID END PRODUCT MANAGEMENT OPTIONS

3. Anaerobic Digester

Source: http://sites.duke.edu/environ398_10_f2010_ct95/?page_id=46

Anaerobic digestion is the biological solid treatment process that stabilizes organic matter in solid end products from WWTP without oxygen. The important byproduct is biogas, which contains methane, carbon dioxide and trace gases. Biogas can be used to produce natural gas (NG), compressed natural gas (CNG), and/or biogas-based electricity. The biogas[2] from a digester must be cleaned of CO2 and trace gases to produce methane (CH4). Biogas is comprised of approximately 60% biomethane, which can be used in several ways:

- Use directly as natural gas.
- Compress it to make compressed natural gas (CNG) and use for transportation sector, called bio-CNG. The amount of bio-CNG[3] is roughly 96.5% of the original biomethane.
- Generated biogas-based electricity. In this case, A reciprocating engine CHP system is employed to generate electricity and the capacity is 2.0 megawatts.

In addition to biogas, another valuable byproduct of anaerobic digestion is class A biosolids that can be sold and used as organic fertilizer.

[2] The biogas ($CH_4 + CO_2 + H_2O$ + trace gases) can be broken down into the following component shares: 55-65% methane gas (CH_4) , 30-40% carbon dioxide gas (CO_2), and 0-5% water vapor, traces of hydrogen sulfide H_2S and hydrogen H_2 (Appels et al. 2008)

[3] http://www.environmental-expert.com/products/biogas-to-compressed-natural-gas-35510.

SOLID END PRODUCT MANAGEMENT OPTIONS

4. Incineration

Source: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/al/newsroom/photos/?cid=nrcs141p2_023017

Incineration or thermal oxidation is a rapid process to dispose of solid end products from a WWTP with the maximum volume. We can use an incinerator to dispose of solids in any and all amounts.

ECONOMIC CONSIDERATIONS

This fact sheet describes the economic considerations relevant to a WWTP when choosing a solid end waste management option. This includes the investment costs, operation and maintenance (O&M) costs, potential revenue, carbon credits and/or renewable energy credits (RECs), and political/regulatory concerns.

1. Investment costs
   a. **Land application**: $48,000 of capital cost
   b. **High-end fertilizer**: See O&M costs
   c. **Digester**: Reciprocating engine CHP systems over 1 MW in size cost $2000/kW to $3000/kW. 1 MGD of influent flow can produce 26 kW of electric capacity.[4]
   d. **Incineration**: $61,504 of capital cost[5]

2. O&M costs
   a. **Land application**: $490 per dry ton of solid
   b. **High-end fertilizer**: About $249.60 per dry ton of solid[6]
   c. **Digester**: An anaerobic digester in this climate requires about 2.3 MMBtu/day/MGD of thermal energy to operate. 1 MGD of influent flow can produce 2.4 MMBtu/day of thermal energy. The estimated cost to generate electricity from anaerobic digester gas is $0.040/kWh.[7]
   d. **Incineration**: $92 per dry ton of solid[8]

3. Potential revenue
   a. **Land application**: This process does not generate any revenue because the treated biosolids are given to farmers for free.
   b. **High-end fertilizer**: The March 2013 price of 30% nitrogen solutions fertilizer is $410 per dry ton[9].
   c. **Digester:** The 2009 average gas price in D.C. was $13.98 per thousand cu. ft.[10] The

[4] U.S. EPA. (2011). Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field.
[5] This figure is an assumption based on our research.
[6] The composting process cost in 2008 was $208 per dry ton of fertilizer, which included $8 per dry ton of capital cost and $200 per dry ton for operation and maintenance cost (EPA 2002; Harkness et al. 1994; Wang et al. 2009), and a 20% management cost was added to that.
[7] U.S. EPA. (2011). Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field.
[8] This figure is an assumption based on our research.
[9] Agricultural Prices, National Agricultural Statistics Service, USDA.
[10] Chittum, A., & Kaufman, N. (2011). Challenges facing combined heat and power today: A state-by-state

2010 average electric rates was 13.84 cents per kWh.

d. **Incineration**: This process does not generate any revenue for the WWTP.

4. Carbon credits and/or RECs
   a. **Land application**: No carbon credits or RECs for the WWTP.
   b. **High-end fertilizer**: No carbon credits or RECs for the WWTP.
   c. **Digester**: Presently there is no carbon pricing scheme in D.C. or any other state-level credits, but digester/CHP systems are eligible for a 10% federal investment tax credit.
   d. **Incineration**: No carbon credits or RECs for the WWTP.

5. Political/regulatory
   a. **Land application**: Sewage sludge must be treated to meet the pollutant concentration levels outlined in § 503.13 of EPA Title 40: Protection of Environment. There may also be some political resistance to land application because of public's concerns about food safety, the spread of pathogens, and unregulated metal contaminants.
   b. **High-end fertilizer**: For produce to be USDA-certified organic, biosolid-based fertilizer cannot be used. Class A biosolids have been treated to reduce bacteria and therefore pose significantly lower risks in terms of pathogens. However, they may still contain unregulated metals.
   c. **Digester**: There have been new federal mandates to reduce greenhouse gas emissions from federal buildings. D.C. recently adopted new interconnection standards, and the local utility (PEPCO) offers standby rates that are favorable for CHP[11].
   d. **Incineration**: This process is a controversial political issue because it emits ash, flue gas, and CO2e into the air, which may have adverse health affects for people. Furthermore, local communities are often highly opposed to having incinerators near their neighborhoods.

assessment. http://www.uschpa.org/files/public/ie111.pdf.

[11] Chittum, A., & Kaufman, N. (2011). Challenges facing combined heat and power today: A state-by-state assessment. http://www.uschpa.org/files/public/ie111.pdf.

ENVIRONMENTAL CONSIDERATIONS

This fact sheet describes the environmental considerations relevant to a WWTP when choosing a solid end waste management option. This includes the net carbon dioxide equivalent emissions, nutrients provided, energy consumption / energy result, and odor problems associated with each option.

1. Net carbon dioxide equivalent emissions (CO2e)[12]
   a. **Land application**
      Emissions: Calculated from transportation biosolids process to land application fields (0.2 ton CO2e / dry ton of biosolids (Brown et al., 2004)).
      Offsets: Calculated based on the amount of biosolids are used instead of fertilizer in farms (0.1 ton CO2e / dry ton of biosolids (Brown et al., 2004)).
   b. **High-end fertilizer**
      Emissions: None.
      Offsets: Calculated based on the amount of biosolids are used instead of fertilizer in farms (0.1 ton CO2e / dry ton of biosolids (Brown et al., 2004)).
   c. **Digestion**
      Emissions: Calculated from transportation by-product (Class A biosolids) to agricultural market (0.2 ton CO2e / dry ton of biosolids (Brown et al., 2004)) .
      Note that: Class A biosolids production is 0.4838 dt per dt of solid end product[13].
      Offsets: Including the benefits from using biogas as natural gas (0.000056 ton CO2e / cubic foot of NG), CNG (0.000054 ton CO2e / cubic foot of CNG), and/or biogas-based electricity (0.00055 ton CO2e / kilowatt hour) (The Climate Registry, 2008).
   d. **Incineration**
      Emissions: Calculated from combustion process (1.443 ton CO2e / ton of biosolids) (The Climate Registry, 2008).
      Offsets: None.

2. Nutrients provided
   a. **Land application**: Nitrogen substance is the main plant nutrient released to the soil from Class B biosolids produced using a lime stabilization process. However, pathogen contamination is a significant concern to farmers.
   b. **High-end fertilizer**: Nitrogen substance is the main plant nutrient released to the soil

[12] amount of greenhouse gas , using the functionally equivalent amount or concentration of carbon dioxide (CO_2) as the reference.
[13] This figure is an assumption based on our research.

from Class A biosolids produced through a composting process.

c. **Digester**: Nitrogen substance is the main plant nutrient released to the soil from Class A biosolids produced using a lime stabilization process.
d. **Incineration**: None.

3. Energy consumption / energy result
    a. **Land application**: Fossil fuel is used (diesel or gasoline) to transport Class B biosolids to land application fields.
    b. **High-end fertilizer**: Fossil fuel is used to transport Class A biosolids to agricultural markets.
    c. **Digester**: Fossil fuel is used for the operational process. However, biogas that contains methane is an end-product of the anaerobic digestion process.
    d. **Incineration**: Fossil fuel is used for the operational process.

4. Odor problems
    a. **Land application**: Lime stabilization does not eliminate odor problem from the production, delivery, and application of Class B biosolids to the field (Gabriel, 2006 and 2007).
    b. **High-end fertilizer**: None.
    c. **Digester**: None
    d. **Incineration**: None

economic concerns. The instructor should encourage the students to fully diagram the solid waste management process and develop a quantitative framework for analyzing the economics. Once each team reaches a decision, they should write up a brief recommendation and present it to the class. In the next 30 minutes, the teams will repeat this process for the *environmental considerations*. At this stage, the instructor should encourage the students to consider this factor in isolation when proposing a solution. For the environmental considerations, students may also draw on any background they have in environmental science, since the fact sheet presents technical data that may need to be put in a larger perspective.

Once the students have considered each factor in isolation, the instructor leads a discussion on how the economic and environmental considerations may interact with each other. In particular, the environmental outcomes (such as odor problems) of different waste management options may have political and health ramifications, which will in turn affect the economics of each option. Furthermore, the uncertainty of future carbon pricing (e.g. a carbon tax) may affect the relative importance of carbon credits and CO2e emissions. Ultimately, the students should realize that solid end product management is a socio-environmental issue and requires synthesis of various types of data.

In the next part, the instructor asks each team to develop a final recommendation for the WWTP's solid end product management that incorporates the economic and environmental considerations along with any additional factors they deem important (drawing from their own backgrounds). The teams must also develop a defensible framework for incorporating this information into their proposed solution (e.g. cost-benefit analysis). Once the teams agree on a final recommendation, they should write a short report summarizing their proposed solution. This should involve a discussion of which factors are most critical, the framework they developed to analyze the data, and how inclusion of multiple types of information changed their recommendation.

Each team will present their final proposed solution to the class in a five minute presentation. The presentation should summarizes their decision framework, final recommendation, and potential shortcomings of their methodology and solution.

The case study concludes with an instructor-lead discussion with the whole class. Some relevant points of discussion are:

- Compare each team's recommendation and their decisionmaking framework.
- How did this decision involve tradeoffs between different factors, and how do you assign importance to one factor over another in that case?

- What additional data do you wish you had that is relevant to this problem?
- Develop a diagram/schematic on the whiteboard detailing the entire process.
- Review actual solutions WWTPs have developed to address this issue, in particular that of the Philadelphia Water Department's Northeast Water Pollution Control Plant, and the Gloversville-Johnstown Joint Wastewater Treatment Facility[16].
- Discuss any of suggested modifications for upper-level courses (see below).

Expected outcomes

This case is designed to highlight how wastewater (and its byproducts) can be used to produce renewable energy and when this solution may be economically viable for the WWTP and environmentally beneficial to the community. As such, the expectation is that most teams will recommend some form of anaerobic digestion process for dealing with solid waste. However, within this general solution, a multitude of options for generating energy exist with their own nuances. The best option will depend on the size of the WWTP, market conditions, and the state regulatory environment, so there is not one "correct" answer. In that sense, the purpose of this case study is to help students develop a framework for analyzing this complex issue, better understand the multifaceted nature of wastewater treatment systems, and appreciate the potential of this largely untapped renewable energy source in the U.S.

Suggested modifications for upper-level courses

1. Resource economics - write out a basic optimization model of the technology and downstream markets under the assumption of profit maximization.
2. Environmental engineering - use U.S. state population data to forecast potential energy production capacity for wastewater under various CHP technologies.
3. Public policy - analyze the regulatory environment for electricity markets in each state and consider how the proposed solution would change in each case.

Sample assessment questions

The authors intend to use this case study activity with a group of 40 undergraduate students in the Spring 2014 semester and assess the students' learning with three assessment questions below.

1. What is the most important point that you learned from this case study?

   Example response:

   - There is no single right or wrong answer. It really depends on the objective, which is a major point of discussion in this case.

[16] U.S. EPA. (2012). Case Study Primer for Participant Discussion: Biodigesters and Biogas. Technology Market Summit.

- One possible way to find the answer is through quantitative methods. However, it is too difficult to find the correct one. We may need more information.

2. Please describe how looking at this as a socio-environmental system helped you choose the optimal solid management system.
   - This question aims to help students understand the nature of a socio-environmental system.
   - Students can apply their knowledge about socio-environmental systems to this exercise.

   Example response:

   - Incineration is not a good idea for disposing of solids because of the negative environmental impact of the burning process and the higher costs than digestion, composting, or lime stabilization.

3. Did you have any initial hypotheses about the optimal solution/recommendation for this problem before completing this exercise? Were you able to test those hypotheses?
   - This question aims to help students understand the process of formulating hypotheses and testing them with appropriate data.

   Examples response:

   - A digester is the best choice if decision makers would like more revenue generating end products. It can produce biogas and biosolids for fertilizer.

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