Final Project

Publisher: CEE 398 PBL (FA15)
Start: Nov 24, 2015
Due: Dec 16, 2015

Project Overview

Produced with Scholar

Fueling Vehicles with CNG

Version 5

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Dec 18, 2015 at 1:00 PM

Executive Summary

This project assessed the feasibility of using methane-laden biogas from the Champaign wastewater treatment plant as a fuel source. The project compares two alternatives: using it for the UIUC campus fleet service vehicles or for the Champaign-Urbana Mass Transit District (MTD) bus system. Urbana Champaign Sanitary District's wastewater treatment process produces biogas, which is currently used for electricity or combusted into the atmosphere. Instead, a system could be created where this biogas is converted into compressed natural gas (CNG) and then used to power a "green" fleet of vehicles. This allows for the methane to do work before being ulitmately released into the atmosphere. While there are many potential uses for it, such as heating buildings or generating electricity, using methane as vehicular fuel has the potential to greatly reduce local vehicular consumption of fossil fuels, thus preventing excessive greenhouse gas emissions.

Unison Solutions specializes in "BioCNG" biogas purification and compression machines, which make the methane within usable as fuel. The cost for each alternative to convert their vehicles and facilities using Unison technology was found by utilizing the infromation from consulting with the head of the campus fleet, Pete Varney and the MTD public records. Based on present worth analyses, MTD has a desirable payback period of 4.5 years, while the UIUC campus fleet has 6.5 year payback period. Net CO2 reduction calculations show that by converting CUMTD's buses to CNG, the atmosphere would be spared of about 14,400 pounds of CO2 per day, while implementing CNG for UIUC's fleet has a net CO2 per day reduction of just 5,275 pounds. Thus, there's an undeniable benefit environmentally as well as shorter paybac converting the Champaign-Urbana Mass Transit District buses to compressed natural gas.

Introduction & Background

Campus Context

The Illinois Climate Action Plan (iCAP) was initially created to address the different ways that UIUC could work to become a more sustainable campus. It's broken down by topic, with goals and objectives related to each subject; subjects include energy conservation, transportation, and water and stormwater. Each year, it is reevaluated by members of the Institute for Sustainability, Energy, And, Environment (iSEE) to consider what progress has been made to address the feasibility of its goals, and to identify what still needs work. The updated 2015 version of the iCAP was just approved by the Chancellor, and one of the objectives listed that still has a lot of room for growth is the third transportation objective related to the goal of reducing emissions: “Conduct a detailed study by the end of FY17 to develop scenarios for complete conversion of the campus fleet to renewable fuels,” (2015 iCAP). Our team member Claire Dodinval’s work on the iSEE Transportation Sustainability Working Advisory Team, she learned about a suggestion from Pete Varney, Director of Transportation and Automotive Services at UIUC’s Facilities and Services department, that UIUC conduct a feasibility study to investigate different renewable fuel options: “Options to be considered might include sustainably-produced biodiesel, compressed natural gas from anaerobic digestion of organic wastes, and electricity from zero-carbon sources such as solar and wind.”

Methane

The CU wastewater treatment plant -Urbana & Champaign Sanitary- creates about 200,000 cubic feet/day of methane as a waste product of their anaerobic digestion process (Schideman, 2015). This is more methane than they can use, so they burn off the excess in flares; when methane combusts, carbon dioxide is created, which is less harmful in the atmosphere than methane. Thus, large amounts of the pollutant are already being emitted, and if the methane combustion process could be used to do work, it would not be for nothing. Methane also burns cleaner than petroleum- based fuels, meaning less emissions per mile driven after a CNG conversion. The environmental benefits, along with the fact that "CNG currently costs about 40 percent less than gasoline" have been enough to incentivize other city-level fleets to implement the tranistion: "natural gas vehicles show an average reduction in ozone-forming emissions of 80 percent compared to gasoline vehicles," (Compressed Natural Gas, 2015). Simply put, the methane biproduct from the wastewater treatment plant has the potential to replace petroleum-based fossil fuels (which are worse for the environment) that are being culled and combusted for the sole purpose of running vehicles.

Resolve

There were two alternatives considered, fueling the University fleet's service vehicles, which addresses the iCAP initiative, or fueling the Champaign-Urbana Mass Transit District buses. This has been done effectively before in the Chicagoland area's "Pace Bus" system (Wilmot, 2010). Although using natural gas would still contribute emissions, our design would be reusing/combusting gas and creating CO2 that has already been unleashed into the carbon cycle because of human waste, rather than culling more fossil fuels from the ground for the sole purpose of running vehicles. Ultimately, assessing the feasibility of using the natural gas produced at the waste treatment plant to fuel UIUC’s campus fleet would be using an untapped resource to address a pressing emissions issue facing the Champaign-Urbana area.

Project Objectives

The feasibility of sourcing methane for fuel distribution was assessed with the help of Unison Solutions and their BioCNG Vehicle Fuel System that works to clean and compress natural gas for vehicle use. The compatibility of compressed natural gas for the campus fleet's service vehicles was compared with that of MTD's buses in order to determine the best fit-alternative for the region. Economic and environmental factors were taken into consideration. The goal of this comparison was to assess whether the environmental benefit of converting vehicles to CNG fuel would be worth the financial costs. Alternative uses for the wastewater treatment plant's compressed methane were also discussed, so as to find another way for excess methane to not go to waste as flares.

General Project Objectives:

1. Utilize the natural gas from the Urbana and Champaign Sanitary that is currently not being used to its fullest potential, in order to benefit the environment.
2. Evaluate different options in converting the natural gas into a useable source of fuel.
3. Conduct a feasibility study to utilize this fuel for both the UIUC Campus Fleet to address the Illinois Climate Action Plan and the Champaign-Urbana Mass Transit District (MTD).

Methodology

The primary objective was to utilize the methane from the Urbana Champaign Sanitary District (UCSD). In order to accomplish this, information was collected from UCSD regarding their daily methane output and how it is currently managed. Moving forward, the focus was to research how to effectively use the methane. Via a conference call, Tony Schilling of Unison Solutions suggested using one of his firm's BioCNG systems that convert biogas into compressed natural gas (CNG), which can power vehicles. Later, BioCNG was deemed capable of cleaning and compressing the large volume of USCD biogas output.

The next step was to find an outlet to implement this fuel. Using methane to generate heat or electricity was considered, based on existing projects like that of the city of Janesville, Wisconsin which uses digester gas from their wastewater treatment plant to generate electricity (Kemp & Lynch, 2012). While methane is commonly used to heat buildings or generate electricity (meaning that there is existing, convenient infrastructure for those uses), a desire to address local environmental concerns tied to vehicular emissions -referenced in the Illinois Climate Action Plan (iCAP)- prompted research in using CNG to fuel the UIUC campus fleet. Pete Varney from UIUC Facilities and Services provided data on various vehicles within the campus fleet such as their average mileage, use, model and replacement rate. Another local use for CNG fuel was the Champaign Urbana Mass Transit District (CUMTD). MTD is a government subsidized entity and therefore all information relevant for this study is available online in their annual reports.

Once sufficient information was collected, economic and environmental assessments were conducted focusing on payback period and reduced CO2 emissions. The payback periods are calculated using a present worth analysis in Figures 1 and 2, while the emissions are found using calculations presented in Figures 4-6 of the following Results and Discussion section. The economic calculations were based on the costs and revenues which are shown in Figure 3. Ultimately the findings favored CUMTD. This result is primarily based on the minimal amount of miles driven by the campus fleet vehicles in contrast to the very large amount of miles that CUMTD averages. A greater number of miles yields more yearly fuel savings and therefore a more desirable payback period, as well as a greater change in emissions.

Results and Discussion

Economic Results

The initial cost to implement a methane to vehicle fuel system at CUMTD includes the cost of the cleaning and compression machines, converting the facility, and converting the engines of the buses to run CNG. The appropriate BioCNG model for CUMTD is the BioCNG 200 system, which will cost $1,000,000. The cost to convert the CUMTD facility to accommodate for the CNG system is $800,000. The cost of converting a diesel engine to burn CNG is $15,000 and we chose to convert 30 buses, which will cost a total of $450,000. 30 buses was chosen because methane production at the wastewater treatment plant can only create enough CNG for 30. A grant called the Biogas and Biomass to Energy Grant, provided by the Illinois Department of Commerce and Economic Opportunity, is available for $225,000 to relieve the economic burden (Johnston 2015). This sums to a net initial cost of of $2,025,000.

CUMTD would use the entire supply of methane to generate the equivalent energy to 833 diesel gallons each day, which is about 304,00 per year. The average price for diesel gas in Champaign county for the past 5 years is $2.50 per gallon, which amounts to an annual savings of $760,000. Based on information provided by Unison Solutions, operation and regular maintenance costs will be $268,000 annually (Schilling 2015). This sums to net annual revenue of $492,000.

Based on these figures, a present worth analysis was used to determine the payback period. An interest rate of 3% was used to best reflect current interest rates.

Figure 1.

$$\$2,025,000 = (\frac{P}{A}, .03, n) * \$268,000$$

$$4.11 = (\frac{P}{A}, .03, n)$$

n = 4.5 years

Likewise, the initial costs to implement a methane to vehicle fuel system for the University of Illinois service vehicles includes the cost of the cleaning and compressing machines, converting the facility, and converting the engine's of the vehicles to run CNG. The appropriate model for the campus fleet is the BioCNG 50 system, which will cost $625,000. The cost to convert the campus fleet facility to accommodate for the CNG system is $100,000. The cost of converting a standard gasoline engine to burn CNG is ~$2,000 and we chose to convert 108 vehicles, which will cost a total of $232,000. The 108 vehicles were chosen based on their annual mileage. The same grant is available for $225,000 to relieve the economic burden. This sums to a net initial cost of of $732,000.

The campus fleet would use a portion of the methane supply to generate the equivalent energy to 269 gasoline gallons each day, which is about 98,260 per year. The average price for diesel gas in champaign county for the past 5 years is $2.30 per gallon, which amounts to an annual savings of $226,000. Based on information provided by Unison Solutions, operation and regular maintenance costs will be $98,000 annually (Schilling 2015). This sums to net annual revenue of $128,000.

Based on these figures a present worth analysis was used to determine the payback period. An interest rate of 3% was used to best reflect current interest rates.

Figure 2.

$$\$732,000 = (\tfrac{P}{A}, .03, n) * \$128,00$$

$$5.72 = (\tfrac{P}{A}, .03, n)$$

n = 6.5 years

The payback period for CUMTD is 4.5 years and the payback period for the campus fleet is 6.5 years. From an economic standpoint, CUMTD is better suited to implement a natural gas to energy system.

Economic Discussion

The first number that needed to be calculated was the initial cost. There were a number of key differences between the installation costs for each option. CUMTD is able to use the entire supply of methane, where the campus fleet can only use about 33%. This means that CUMTD needs a larger, and more expensive, system to process the natural gas. The engine conversion costs are also far greater for CUMTD, since diesel engines are much more expensive to convert to run on CNG. The facility at CUMTD will also be considerably more expensive to convert. The electric and lighting will need to be completely re-wired in order to make it spark proof, since the methane gas is flammable. Both facilities will need to be outfitted with an emergency shut-off system in case of an emergency. Both projects are eligible for the Biogas and Biomass to Energy Grant that is offered by the Illinois Department of Commerce and Economic Development. In summary, CUMTD is a larger project meaning it is also a larger investment.

This project will produce revenue by offsetting fuel costs. By indexing fuel prices for the last five years we determined that $2.50 per gallon of diesel and $2.30 per gallon of gasoline is an accurate average price. Since CUMTD is able to use the full 120,000 ft3 methane produced each day, CUMTD will be able to offset 833 gallons daily. The 108 fleet vehicles chosen for conversion only burn 269 gallons each day. This is why CUMTD has such greater annual savings compared to the campus fleet. As far as annual costs, the larger machine that CUMTD would run uses more electrical power and requires a higher degree of maintenance. Maintenance is mostly referring to regularly replacing the filter that cleans and isolates the methane. The larger machine processes more methane per day, which means the filter must be replaced more often. Thus, annual operating costs are much higher for CUMTD.

The campus fleet simply does not have the mileage necessary to generate the annual savings that are necessary to make such a large initial investment. The longer payback period for the campus fleet supports this conclusion.

Specific Costs, Assumptions and Calculations:

- BioCNG 200 System - $1 million
- BioCNG 50 System - $625,000
- CUMTD Facility Conversion - $800,000
- University of Illinois Facility Conversion - $100,000
- Diesel Engine Conversion - $15,000/engine
- Regular Engine Conversion - $2000/engine
- Price of Diesel Fuel - $2.50/gallon
- Price of Regualr Fuel - $2.30/gallon
- Average operational costs provided by Unison Solutions

Figure 3. Summary of costs and expected revenue

Implementation Cost		
	CUMTD	**Campus Fleet**
Costs:		
Equipment	$1,000,000	$625,000
Engine Conversion	$450,000	$232,000
Facility Conversion	$800,000	$100,000
Savings:		
IL DCEO Grant	$225,000	$225,000
Net Cost	**$2,025,000**	**$732,000**
Yearly Revenue		
Savings:		
Fuel Savings	$760,000.00	$226,000.00
Costs:		
Operation and Maintenance	$268,000.00	$98,000.00
Net Yearly Revenue	**$492,000.00**	**$128,000.00**

*Data above provided by Pete Varney, the CUMTD website/ annual reports, Tony Schilling and Unison Solutions in 2015.

Findings:

The payback period was determined using a present worth analysis. The analysis was run with an interest rate of 3% to best reflect current interest rates. The results were a payback period of 4.5 years for CUMTD and a payback period of 6.5 years for the campus fleet.

Environmental Results

Data:

The following information summarizes the respective energy use, fuel production and consumption, and emissions of each component tied to converting UCSD's methane into usable fuel that replaces existing, petroleum-dependent fleet infrastructure.

Figure 4. Standard emissions calculation applied to UCSD, UIUC Fleet, and CUMTD components (unit conversions were sometimes used)

$$\frac{Quantity\ of\ Fuel\ Combusted}{Day} * \frac{CO2\ Emitted\ (Emission\ Factor)}{Quantity\ of\ Fuel\ Combusted} = Resultant\ Emissions\ of\ CO2$$

Figure 5. Emissions calculation applied to BioCNG System (unit conversions were used)

$$\frac{Energy\ Usage\ (kW)}{Hour} * \frac{24\ Hours}{1\ Day} * Ameren\ Combined\ Emission\ Factors = Resultant\ Emissions\ of\ CO2$$

-UCSD Wastewater Treatment Plant

- 120000 cubic feet of Methane/ day generated as part of biogas biproduct
- Natural Gas Emission Factor: 120,000 lb CO2/ 10^6 cubic feet of Methane (EPA)
- Resultant daily CO2 emissions from plant due to methane (assuming all methane combusted either in waste flares or to generate UCSD plant electricity)= 14400 lb CO2/ day (See Figure 4)

-BioCNG

- Estimated electrical usage: 165 Amps @ 480V/ 3Ph/ 60Hz (137 kW/ hr.) (Schilling 2015)
- Electricity sourced from Ameren in Champaign, which uses a combination of fuels with respective emission factors (natural gas: see above, and coal: 5808 lb CO2/ ton coal, assuming coal is 80% Carbon) (Johnston 2015) (EPA)
- Resultant daily CO2 emissions from operating for 24hr/day using Ameren electricity = 4603 lb CO2/ day (See Figure 5)

-Campus Fleet

- Gallons Gasoline Equivalent to Daily UCSD Wastewater Treatment Plant Methane Production: 941 gal/ day
- Gasoline Emission Factor: 19.6 lb CO2/ gal Gasoline (EPA)

- Resultant daily CO_2 emissions from campus fleet service vehicles, before scaling by utilization= 18444 lb CO_2/ day (See Figure 4)
- Utilization of 12000 cubic feet of Methane/ day generated by plant= 28.6%

-CUMTD

- Gallons Diesel Equivalent to Daily UCSD Wastewater Treatment Plant Methane Production: 833 gal/ day
- Diesel Emission Factor: 22.4 lb CO_2/ gal Diesel (EPA)
- Resultant daily CO_2 emissions from MTD buses, before scaling by utilization= 18659 lb CO_2/ day (See Figure 4)
- Utilization of 12000 cubic feet of Methane/day generated by plant= 100%

*Data above provided by the US EPA, Morgan Johnston, and Tony Schilling in 2015.

Findings:

The 14,400 pounds per day CO_2 emission from the wastewater treatment plant is dependent on UCSD's biogas production, and will occur regardless of whether a CNG fleet project is implemented. However, if the project goes forward, this daily CO_2 output will replace emissions due to operating the gas or diesel engines of a fleet, because the methane will have been put to work. The CO_2 released by operating the BioCNG machine will be the only new source of emissions post-conversion, and this 4,600 pounds of CO_2 per day is much less than the current petroleum-engine emissions tied to running the fleets.

Figure 6. Net CO2 emissions reduction calculation

$$(CO2\ emissions\ from\ UIUC\ Fleet\ or\ MTD - BioCNG\ Emissions) * Utilization = Net\ Reduced\ CO2$$

Potential net CO_2 reduction was used as a general environmental indicator (see Figure 6). Reduction was considered as CO_2 emissions from the fleet or MTD less the emissions used to operate BioCNG, then scaled by methane utilization. The results were 5275 lb CO_2/ day reduced for UIUC campus fleet service vehicles and 14056 lb CO_2/ day for the CUMTD bus system. In simpler terms, converting CUMTD to natural gas eliminates more than 2.5 times more carbon dioxide pollution than would be reduced by converting the campus fleet.

Environmental Discussion

In order to determine the environmental benefits of converting to CNG, the two options were analyzed considering the potential emissions that could be reduced for each. For this analysis, carbon dioxide (CO_2) was used as a representative of the general environmental benefit because methane releases CO_2 during combustion, and because CO_2 emissions are a standard emissions indicator. CO_2 is one of the primary greenhouse gases that affect climate change.

Regardless of the vehicle alternative selected, switching to CNG benefits the environment. Currently, the Urbana Champaign Santiary District creates 200,000 cubic feet of waste gas per day; 60% of which is methane: 120,000 cubic feet (Schideman, 2015). Some is converted to electricity (a process which creates emissions), and what cannot be used is burned off in flares as CO_2. Considering emission factors, that's altogether an equivalent 14,400 pounds of CO_2 per day released to the atmosphere (External Combustion Sources, 2015). With or without the BioCNG system, that pollution will make its way to the environment- but without implementing the fuel conversion, there are additional greenhouse gases being released when gasoline or diesel is burned to run vehicles in Champaign-Urbana. The 120,000 cubic feet per day of compressed natural gas has a fuel equivalent of 941 gallons of gasoline or 833 gallons of diesel. Considering EPA emission factors again, if the fleet vehicles were to burn that equivalent amount of gasoline, they would release about 18444 pounds of CO_2 daily. Likewise, if MTD buses burned that equivalent amount of diesel daily, they would be emitting about 18659 pounds of CO_2 (External Combustion Sources, 2015). It must be noted that running the BioCNG machine will pull electricity from the standard grid at a rate of 137kW per hour, adding to the carbon dioxide emissions of the switch. Assuming that the macine runs for 24 hours per day, the resultant

CO2 emissions of compressing and cleaning UCSD's biogas would be 4603 pounds of CO2 per day (Johnston, 2015). A net reduction of about 14,000 pounds per day of CO2 emissions results for both fleets, but the key difference between the fleet alternatives is that the UIUC campus fleet doesn't drive enough miles daily to consume the 941 gallons of gasoline equivalent to 120,000 cubic feet of methane: it uses about 30% of that. When the campus fleet's net CO2 emission reduction was scaled by its methane consumption, its net reduction of pounds per day of CO2 emissions is just 5275 pounds. Since converting the MTD buses uses all available methane (a methane utilization factor of 100%) converting CUMTD to CNG proved to have a much larger benefit to the environment: just over 14,000 pounds of CO2 per day eliminated. Thus, converting CUMTD's buses is the optimal alternative environmentally.

Conclusions

Ultimately our results indicated that Champaign-Urbana Mass Transit District is a better fit, based on payback period and environmental impact, to implement a natural gas to fuel system. The payback period for CUMTD of 4.5 years is more desirable than the campus fleet's pack back period of 6.5 years. From an environmental standpoint, CUMTD also offsets more than 2.5 times more carbon dioxide pollution than the campus fleet since it is able to fully utilize the methane supply; converting CUMTD to CNG would eliminate about 14,000 pounds of CO2 emissions per day. In the end, it came down to the simple fact that the campus fleet does not have the mileage to utilize the entire supply of methane from UCSD, which was the primary project objective. Less methane used means that less gasoline expenditures are offset which increases the payback period of a large initial investment, such as the BioCNG system. Thus, CUMTD is far better economically and that is the biggest reason why it is the more desirable option. CUMTD also has a greater positive impact on the environment although generally that is due to the scale of the CUMTD alternative compared to the campus fleet alternative. The Champaign-Urbana Mass Transit District has the mileage to support converting to CNG, meaning a faster return-on-investment and a greater environmental benefit.

Acknowledgments

Special thanks to:

Professor Lance Schideman, Ph.D., P.E.; Assistant Professor of Agricultural and Biological Engineering, Agricultural Engineering Sciences

Peter Varney; Director of Transportation and Automotive Services, Facilities & Services.

Tony Schilling; Unison Solutions, Inc.

Morgan Johnston; Associate Director of Sustainability within UIUC Facilities & Services.

James Bittner, Civil and Environmental Engineering- Project Based Learning Teacher's Assistant.

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Budget

Fortunately, no money was spent in doing the research necessary for this project.

Group Reflections

This project has been an exceptional experience from start to finish. At the very beginning we were taught how to address a current issue and design an engineering project to create a solution. We originally started with a different project focusing on developing a stronger bike path infrastructure. After making observations regarding potential additions along with examining the current bike path it was found that there is in fact an existing well-developed system. This was a major setback right from the start. Although it was disappointing to be forced abandon our initial project, we knew that we had to move forward. When searching for a new project we received a great deal of support of the CEE 398 teaching staff and ultimately decided to investigate an application for the excess methane produced at the wastewater treatment facility. Professor Lance Schideman recommended that we investigate using the methane to fuel the University of Illinois service vehicles.

We immediately began to BioCNG receive a great amount of hands on experience. Information was collected from a variety of sources such as facilities and services along with the Urbana Champaign sanitary district. Consulting with professionals within the field such as Peter Varney and Tony Schilling developed our communication and networking skills which is something not explicitly taught in the typical classroom. One thing that we would do differently would be to work on time management. We were able to meet deadlines, gather information and keep our work organized. However, we may have procrastinated a little too much at certain points throughout the semester. In the end, we felt good about what we were able to accomplish during the semester. We are confident that our report is a good general indicator of the feasibility of this project and we look forward to potentially taking the next step.

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