# San Francisco Public Utilities Commission Southeast Treatment Plant

## Financial and Environmental Assessment of Biomethane as Transportation Fuel

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## Table of Contents

## Executive Summary

The San Francisco Public Utilities Commission's Southeast Treatment Plant has been producing renewable electricity from its anaerobic digesters for several years. However, a number of team members feel that this renewable fuel is not being utilized in a way that maximizes public value. First, the fuel is being used to offset electricity that is already carbon-neutral, as San Francisco municipal entities receive their electricity from large hydropower. Second, combustion of such fuel creates particulate emissions that are dispersed to the surrounding neighborhood, disproportionately affecting those who live and work near the plant. And third, the financial value of this fuel could be higher if it were sold and utilized as a transportation fuel.

After evaluating four transportation fuel scenarios, the Presidio Graduate School team determined that there was in fact a viable solution to produce and distribute biomethane as a transportation fuel for use in compressed natural gas vehicles. By prioritizing the production of biomethane and utilizing equipment from the manufacturer BioCNG, the SFPUC could potentially earn up to $1.1 million per year from the sale of transportation fuel. In addition, this scenario would eliminate over 15,000 metric tons of greenhouse gas emissions by displacing fossil fuel-based compressed natural gas in vehicles. Lastly, this scenario would alleviate the harmful effects of particulate emissions and better care for the surrounding community. Thus, this option is a true win-win-win.

## Key Assumptions

### Physical Attributes

The following ten physical inputs play vitally important roles in the outcomes produced by the valuation model. The descriptions that follow identify the assumed values, as well as provide an explanation of the input and its importance. Although most of these inputs are constant, we believe that the sensitivity of cogeneration operating uptime and boiler heating demand are the most important drivers of the valuation model.

*Figure 1: Physical Inputs*

| | |
|---|---|
| (1) Boiler Heating Demand | 0.223 MMBTU/min<br>or 352 SCFM @ 635 HHV |
| (2) High Heating Value of Road Fuel | 1025 BTU/SCF |
| (3) High Heating Value Of Biogas | 635 BTU/SCF |
| (4) Heating Value per GGE | 125,000 BTU |
| (5) Cogeneration Electricity Output at Southeast Treatment Plant | 1.8 MW |

| | |
|---|---|
| (6) Electricity Demand at Southeast Treatment Plant | 4.4 MW |
| (7) Cogeneration Operating Uptime | 60% |
| (8) Carbon Intensity of Gasoline (g CO2e/MJ) | 96.48 |
| (9) Carbon Intensity of CNG (g CO2e/MJ) | 67.70 |
| (10) Carbon Intensity of Wastewater Biogas (g CO2e/MJ) | 7.89 |

1. *The boiler heating demand* is the amount of heating required by the two boilers on site at Southeast Treatment Plant to maintain a constant temperature of 95°F within the anaerobic digesters. Doing so allows the digesters to mimic the natural process of digestion and break down organic solids so less waste is generated. In addition, a byproduct of this process is methane gas, which can be captured and reused to heat the boilers or utilized in other ways such as cogeneration or road fuel.

   This input is significant to the valuation model because it determines the amount of biogas and/or natural gas that is required to maintain the boilers at 95°F and therefore is a cost driver across Scenarios B through E.

2. *The high heating value of road fuel* is the amount of heating energy that is available in one standard cubic foot of road fuel. This is the amount of energy that remains in each SCF after biogas is processed through the membrane to be used as road fuel in CNG vehicles.

   This input is significant to the valuation model because it determines the amount of biogas that is available to use as road fuel after the membrane process and is a driver of revenue available in each scenario.

3. *The high heating value of biogas* is the amount of heating energy that is available in one standard cubic foot of biogas. This is the amount of energy that each SCF of conditioned biogas contains after being processed by the conditioning skid.

   This input is significant to the valuation model because it determines the amount heating that can be derived from biogas to satisfy the digesters and is a cost driver across Scenarios B through E.

4. *BTUs per gas gallon equivalent* is the amount of heating energy that is available in one GGE. This is the amount of energy that is contained in the equivalent of one gallon of gasoline.

   This input is significant to the valuation model because it determines how many GGEs are available to sell as road fuel and is a driver of revenue across Scenarios B through E.

5. *Cogeneration electricity output* is the amount of electricity that can be produced in one hour by the existing cogeneration facility at Southeast Treatment Plant. This amount is determined by the rated power of the machinery installed.

   This input is significant to the valuation model because it determines the amount of electricity that can be generated onsite from biogas and is a driver of revenue (in avoided costs) in Scenario A.

6. *Electricity demand at Southeast Treatment Plant* is the average amount of electricity that the treatment plant consumes every hour. This is determined by estimates from the SFPUC staff and represents the total amount of electricity required by the plant.

   This input is significant to the valuation model because it determines the total amount of electricity that the treatment plant requires and can be used to determine the percentage of electricity needs met by Scenario A.

7. *Cogeneration operating uptime* the average amount of time that the cogeneration facility is operating on an annual basis. This is determined by analysis of the site by SFPUC engineers and evaluates how many hours the equipment was functioning out of the total available hours.

   This input is significant to the valuation model because it determines the amount of electricity generated by the cogeneration facility and is a main driver of revenue (in avoided costs). Increasing this value closer to 100% would make the net present value of Scenario A nearly equal to that of Scenario E.

8. *The carbon intensity of gasoline* is the amount of greenhouse gas emissions produced for every one megajoule of energy consumed as gasoline. This input takes into account the total lifecycle of the fuel from extraction to use within a vehicle.

   This input is significant to the valuation model because it determines the amount of greenhouse gas emissions that would be produced by using gasoline as road fuel and also determines the value of California Low Carbon Fuel Standard credits that are available to producers of biogas. Per the SFPUC's suggestion, we have utilized this as a base case for determining the potential greenhouse gas emissions savings by displacing fossil fuel in vehicles.

9. *The carbon intensity of compressed natural gas* is the amount of greenhouse gas emissions produced for every one megajoule of energy consumed as compressed natural gas. This input takes into account the total lifecycle of the fuel from extraction to use within a vehicle.

This input is significant to the valuation model because it could determine the amount of greenhouse gas emissions that would be produced by using compressed natural gas as road fuel and the amount of greenhouse gas emissions savings generated by using biogas as an alternative fuel.

10. *The carbon intensity of biogas* is the amount of greenhouse gas emissions produced for every one megajoule of energy consumed as biogas. This input takes into account the total lifecycle of the fuel from production to use within a vehicle.

    This input is significant to the valuation model because it determines the amount of greenhouse gas emissions that would be produced by using biogas as road fuel and also determines the value of California Low Carbon Fuel Standard credits that are available to producers of biogas. In addition, this input determines the amount of greenhouse gas emissions savings generated by using biogas as an alternative fuel.

**Financial Attributes**

The following twelve financial inputs play vitally important roles in the outcomes produced by the valuation model. The descriptions that follow identify the assumed values, as well as provide an explanation of the input and its importance. Although all of the inputs are important, we believe that the sensitivity of the delivery cost, RIN value, and LCFS credits are the most important inputs to the model.

*Figure 2: Financial Inputs*

| | |
|---|---|
| (1) Delivery Cost per GGE | $3.00 |
| (2) RIN Value per GGE | $0.64 |
| (3) LCFS Value per Metric Ton | $100 |
| (4) Cost of Electricity per Kilowatt | $0.12 |
| (5) Cost of Natural Gas per MMBtu | $2.42 |
| (6) Cost of CNG per GGE | $2.49 |
| (7) Annual Senior Stationary Engineer Salary | $148,278 |
| (8) Annual Stationary Engineer Salary | $138,045 |
| (9) Clean Methane Solutions Development Cost | $5,500,000 |
| (10) BioCNG Development Cost | $2,950,000 |
| (11) Clean Methane Solutions Annual Operational Cost | $500,000 |
| (12) BioCNG Annual Operational Cost | $8,000 |

1. The *delivery cost* per gas gallon equivalent is the cost associated with bringing compressed biomethane to market for sale and use within CNG vehicles. This rate was determined through conversation with a potential delivery provider, Ultimate CNG.

   This input is significant to the valuation model as it is the sole variable cost associated with the manufacturing and distribution process of biomethane.

2. The *RIN value per GGE* is the credit value identified by the federal government per gas gallon equivalent of biomethane.

   The value of RIN credits are vitally important to the success of this project, as it, in combination with the value of state LCFS credits, make the distribution of road fuel a profitable endeavor. RIN credits can be sold on the open market. From a risk perspective, there is very small potential that these credits will be removed from the marketplace as the demand for these credits has increased alongside the Federal Renewable Fuel Standard, which dictates the minimum level of domestically produced renewable transportation fuel.

3. The *LCFS value* is the credit value identified by the state of California per metric ton of greenhouse gas emissions. Organizations that are unable to meet mandated reductions in greenhouse gas emissions, such as oil producers, are able to purchase reductions in the form of LCFS credits from buyers, such as renewable fuel manufacturers, on an open market. This model relies on the principles are cap and trade enacted under California's Global Warming Solutions Act (Air Resources Board, 2015).

   The value of LCFS credits are vitally important to the success of this project, as it, in combination with the value of Federal RIN credits, make the distribution of road fuel a profitable endeavor. LCFS credits can be sold on the open market. From a risk perspective, there is very small potential that these credits will be removed from the marketplace as the demand for these credits has increased alongside California's Low Carbon Fuel Standard Program.

4. The *cost of electricity per kilowatt* is the price that the SFPUC pays to Pacific Gas & Electric (PG&E) for the distribution of energy to its facilities.

   This input is significant because it is the main driver of avoided cost in business as planned operating cogeneration. For the purposes of this analysis, the additional cost to operate the Southeast Treatment Plant should the SFPUC no longer using biogas to offset a portion of their electricity needs has not been included in the alternative scenarios as this is a cost the SFPUC will face to operate the plant regardless. Doing so allows teams to isolate the best utilization of the biogas asset.

5. The *cost of natural gas per MMBtu* is the price that the SFPUC pays to PG&E for any additional natural gas that is needed to heat the digesters.

   This input is important for the valuation model in scenarios D and E because it is used to calculate the added PG&E cost in those scenarios where the production of road fuel is prioritized, leaving the needs of the digesters unmet.

6. The *cost of CNG per GGE* is the market price that consumers pay for vehicle-grade compressed natural gas at the pump in Northern California. Therefore, this number is used as the predicted commodity price of biomethane.

   This input is significant to the valuation model because it determines the commodity price that the SFPUC must meet in selling its biomethane to match existing market conditions. Although $2.49 is lower than the $3 cost of delivery, the added RIN and LCFS credits of $1.81 yield a total gross profit per GGE of $1.30.

7. The *annual senior stationary engineer salary* is the cost to employ one of the engineers needed to operate the cogeneration facility and cleaning skid in Scenario A. Scenario A utilizes one FTE of an annual salary, but only 10% of one FTE in Scenarios B through E as they only operate the cleaning skid.

8. The *annual stationary engineer salary* is the cost to employ the engineers needed to operate the cogeneration facility and cleaning skid in Scenario A. Scenario A utilizes two FTE of an annual salary, but only 10% of one FTE in Scenarios B through E as they only operate the cleaning skid.

9. The *development costs associated with Clean Methane Solutions* include the labor and equipment needed to install equipment that produces and compresses biogas into road fuel. Clean Methane Solutions proposed an all-new dual membrane setup that would not utilize any of the SFPUC's existing equipment, thus resulting in a higher proposed cost than of BioCNG.

   This input is significant to the valuation model because it is the sole fixed cost associated with scenarios B and D.

10. The *development costs associated with BioCNG* include the labor and equipment needed to install equipment that produces and compresses biogas into road fuel. BioCNG proposed a single membrane setup that would utilize a portion of the SFPUC's existing equipment, thus resulting in a lower proposed cost than of Clean Methane Solutions.

    This input is significant to the valuation model because it is the sole fixed cost associated with scenarios C and E.

11. The *annual operating costs associated with Clean Methane Solutions* account for the salaries and maintenance costs needed to maintain the additional equipment.

    This input is important to the valuation model because it is a rather significant annual cost in scenarios B and D. However, the $500,000 annual cost may be overestimated. The actual maintenance costs are likely closer to those of Scenario A or possibly even lower. This number does not include the additional costs associated with maintaining the cleaning skid.

12. The *annual operating costs associated with BioCNG* account for the salaries and maintenance costs needed to maintain the additional equipment.

    This input is important to the valuation model because it is a recurring annual cost in scenarios C & E. However, we believe that the $8,000 annual cost is underestimated. The actual maintenance costs are likely still less than Scenario A, but more than this number. This number does not include the additional costs associated with maintaining the cleaning skid.

**NPV Assumptions**

1. The cash generated by the project is immediately reinvested to generate a return at a rate that is equal to the opportunity cost of capital of 2.05%, which is equal to the average rate of inflation between 2005 and 2015.

2. The inflow and outflow of cash other than the initial investment occurs at the end of each period.

## Methods of Analysis

**Opportunity Cost of Capital**

The SFPUC receives their annual interest-free budget from state and federal sources. Therefore, for relatively small projects such as this one, the SFPUC does not traditionally account for cost of capital in their financial forecasts. However, for the purposes of this report, we applied the industry standard documented in the deRuyter Feasibility Study, published in 2012 by Washington State Department of Commerce, which applies an opportunity cost of capital that is equal to the current inflation rate.

For the SFPUC, the deRuyter case study is a compelling example that evaluates remediation techniques and offtake markets for renewable natural gas at the deRuyter Dairy plant. We believe that the deRuyter Feasibility Study describes a comparable project and demonstrates good economics by using an average inflation rate for the cost of capital.

Furthermore, setting a relatively low opportunity cost of capital is appropriate for the SFPUC because they have an unusually large annual capital improvement expenditures budget from which a $5 million investment is negligible. The capital infrastructure, which is required to implement our project, including biogas scrubbing, compression, and conditioning, is $7 million less than the allocated budget.

Therefore, given the current inflation rate of 0% and the inherent variability of the metric, our team decided that it would be more realistic to apply an opportunity cost of capital equal to the average inflation rate over the past 10 years, or 2.05% between November 2005 and November 2015.

**Net Present Value (NPV)**

NPV allows for project teams and investors to determine whether or not they should invest in a project. By using discounted future cash flow, teams can determine with greater accuracy if a project is actually worthwhile after subtracting out the initial cost. If a project has an NPV above zero, then the project is said to be worthwhile.

**Profitability Index**

After determining which projects are considered to be worthwhile using NPV, profitability index helps project teams determine which project to pursue when considering multiple viable options. By dividing the NPV by the initial investment required, teams can identify which project has the greatest profitability with the least investment.

**Internal Rate of Return (IRR)**

IRR allows project teams to determine whether or not a project is financially viable by assessing non-discounted cash flows and providing a percentage return on the initial investment. Using an organization's predetermined IRR threshold, if the project IRR is greater than the threshold IRR, the project is considered to be financially viable.

**Payback Period**

Payback period determines the amount of time required to recoup the initial investment using non-discounted cash flows. For this reason, it is sometimes referred to as simple payback period. Using this metric, project teams can determine which investment has the shortest payback and when the project will begin earning cumulative profits.

**Net Greenhouse Gas Emissions Savings**

Net greenhouse gas emissions savings is derived from the total carbon dioxide equivalent saved by utilizing biogas as a road fuel less any emissions from combusting natural gas when compared to business as planned. It is important to assess both the financial benefit as well as the environmental benefit in a quantifiable way to determine the best scenario for the public good. With business as planned being the control, all four road fuel scenarios provide significantly greater greenhouse gas emissions savings.

**Social Return on Investment**

Social return on investment is a metric used to assess the value of a project that cannot be encapsulated in financial metrics. It accounts for social, economic, and environmental factors. In this valuation, the primary benefits of pursuing Scenarios B through E are manifest in the form of improved environmental health of the neighborhood surrounding Southeast Treatment Plant as well as the overall reduction in greenhouse gas emissions by substituting biogas for compressed natural gas in vehicles.

## Financial Scenarios

All four of the potential road fuel scenarios analyzed utilize a 10-year cash flow projection as well as all of the seven aforementioned valuation tools and similar financial and physical input assumptions. The 10-year time frame was chosen based on the SFPUC's plans to divert all biogas to cogeneration in 2025. Differences in the valuations are driven by variations in the fixed costs, equipment efficiencies, and processes flows associated with each scenario.

To adequately compare business as planned to the four alternative road fuel scenarios, business as planned was set to have a net present value equal to $0 and provided the base case despite the fact that cogeneration provides cost savings through electricity production. Since this is already happening though, we wanted to be clear that pursuing Scenario A would not generate any additional benefit. To account for the lack of cost savings due to cogeneration's operation in alternative road fuel scenarios, the projected electricity cost less cogeneration's operating cost was added to the overall operations and maintenance costs across all four scenarios.

*Figure 3: Scenario Descriptions*

| Scenario | Equipment Manufacturer | Cost | Efficiency | Process |
|---|---|---|---|---|
| A | N/A | N/A | N/A | Electricity Cogeneration |
| B | Clean Methane Solutions | $5.5M | 95% | Digester 1st, Road Fuel 2nd |
| C | BioCNG | $2.95M | 70% | Digester 1st, Road Fuel 2nd |
| D | Clean Methane Solutions | $5.5M | 95% | Road Fuel 1st, Digester 2nd |
| E | BioCNG | $2.95M | 70% | Road Fuel 1st, Digester 2nd |

**Recommended Scenario - Scenario E**

In the recommended scenario, we propose that the SFPUC pursue developing road fuel by utilizing the BioCNG membrane system and prioritizing road fuel production over digester heating needs. The total capital expenditure and operating costs for this equipment were the lower of the two options at $2.95 million and $8,000 per year, respectively. Part of the reason for the lower capital and operating costs associated with BioCNG is attributed to the reuse of existing equipment already at Southeast Treatment Plant. In particular, the conditioning skid, which is in place to provide conditioned biogas to the cogeneration facility, can be reused for the production of road fuel prior to sending biogas to the membrane system. Prioritizing road fuel over digester heating does result in nearly $90,000 in additional costs for natural gas to make up the difference, but this number is more than made back through the sale of biomethane as a road fuel.

This scenario is the most desirable because it contains the best performance across all four financial metrics with an NPV of nearly $7 million, a profitability index of 2.34, an IRR of 36%, and a payback period of only 2.68 years. Its environmental benefit was second only to Scenario D with 15,602 metric tons of carbon dioxide equivalent saved per year, however, these savings are not drastic enough to outweigh the more desirable financials of Scenario E. Using the Scenario's profitability index and IRR were especially useful in assessing this scenario against Scenario D, which has a greater environmental benefit and seems to have a relatively similar NPV. However, with over twice the profitability relative to initial investment and internal rate of return, the decision was quite clear.

**Alternate Scenarios**

1. *Scenario A* considers the operation of Southeast Treatment Plant's cogeneration facility under business as planned. Doing so would continue the practice of utilizing biogas first to heat the digesters and second to produce electricity for the plant, with the remainder being flared to avoid releasing raw methane. Operating cogeneration produces heat as a byproduct, which can be used to provide part of the digesters heating requirement, thus lowering the amount of biogas required to do so. However, this additional biogas is being flared anyway so its value is not being maximized.

   This scenario does not require any initial investment nor have we set it to demonstrate any additional financial gain. However, we have calculated the amount of electricity generated and thus identified the value of its cost savings based upon the operating uptime of the cogeneration plant, a significant driver of its financial viability. With the current operating uptime at 60%, a number considered to be generous by the SFPUC, the value of cost savings are equal to $725,328. In essence, only 60% of cogeneration's potential value is being realized. If this number were to approach 100%, its value would approach nearly twice that. However, this sort of operating efficiency is not technically feasible as the machinery cannot be kept up and running every hour of the day. In addition, there are no environmental savings in the form of road fuel and the social impact on local residents is not being addressed. Therefore, even with a more operational cogeneration facility, this scenario is still less desirable than the recommended scenario utilizing biogas as road fuel.

2. *Scenario B* utilizes Clean Methane Systems membrane systems, a more efficient but more costly piece of equipment, and prioritizes digester heating over road fuel production. As one might expect, this scenario has the worst financial valuation metrics of the alternative scenarios due to the large upfront cost and underutilization of valuable road fuel. Its NPV is negative by over $2 million and both its profitability index and IRR are negative as well. To make matters worse, the payback period is over 17 years, far beyond the 10-year time horizon given.

3. *Scenario C* utilizes the same process flow as Scenario B but instead considers the use of equipment from BioCNG. BioCNG's equipment is less expensive, both in initial capital

expenditure and in annual operating costs, but it is also less efficient. Despite this, it yields significantly better results across all four financial metrics than Scenario B.

This scenario, with BioCNG, has an NPV over $4 million, a profitability index of 1.5, an IRR of 24%, and a payback period of under 4 years. Because the same amount of road fuel is produced across both Scenarios B and C, the net greenhouse gas emissions savings are the same. Therefore, these two scenarios can simply be compared based on financial metrics, and Scenario C is significantly better when compared to Scenario B based solely on financials.

4. *Scenario D* reverts back to the more expensive, more efficient equipment from Clean Methane Solutions, but changes the process flow to send all available biogas through the membrane equipment first rather than diverting flow to the digesters. Doing so maximizes the available biogas that can be converted into road fuel, which has a higher market value.

   The process flow in this scenario allows for a higher percentage of biogas to be converted into biofuel, but not without additional annual cost of over $250,000 for natural gas to heat the digesters from PG&E. This additional cost is substantial, totaling over $2.5 million over 10 years. The outcome is the second highest NPV of all five scenarios nearly $5 million, but a longer payback period of nearly 5 years, an IRR of 16%, and profitability index just less than 1.

*Figure 4: Scenarios Comparison Dashboard*

| | **Scenario A** | **Scenario B** | **Scenario C** | **Scenario D** | **Scenario E** |
|---|---|---|---|---|---|
| **NPV 10-Year** | $0 | ($2,670,339) | $4,287,554 | $4,748,184 | $6,917,094 |
| **Profitability Index** | n/a | -0.49 | 1.5 | 0.86 | 2.34 |
| **IRR** | n/a | -9% | 24% | 16% | 36% |
| **Payback Period (years)** | n/a | 17.41 | 3.65 | 4.81 | 2.68 |
| **Annual $CO_2e$ (metric tons)** | n/a | 14,120 | 14,120 | 18,300 | 15,602 |

*Note: green highlight identifies the best result among the four scenarios*

## Conclusion

### Key Insights

Over the course of the project, the scope of work evolved from simply evaluating business as planned against a single road fuel scenario to evaluating various delivery methods for road fuel to the final scope which simply evaluated the equipment and process flow for four road fuel scenarios. This was important to help clarify the expectation and product a quality work with the information and time constraints given.

As a next step, the SFPUC can consider which delivery method is best for their road fuel program now that it has been established that road fuel is financially viable. For the purpose of this analysis, delivery was assumed to be $3 per GGE based upon the estimate of Virginia-based Ultimate CNG. The SFPUC would likely begin with an arrangement such as this to demonstrate viability and then move to purchase their own delivery equipment, keeping a larger share of the profit from each GGE.

### Challenges & Solutions

Various challenges exist with making a road fuel program viable and ultimately operational. The financial valuation presented assumes that every GGE produced is sold, however, it has already been determined that this level of production is more than the entire City of San Francisco municipal CNG fleet could consume in a year. Therefore, the SFPUC will need to find additional customers for its road fuel. It was fairly challenging to grasp the nuances of the federal and state incentive programs, including calculations of available credit per GGE. Having enlisted the help of an energy trader, the SFPUC has already begun to assess the feasibility of using such credits in a road fuel program. Clearly, these are complex issues that require the help of external experts to ensure accuracy and completion of credit applications and ultimate disbursement.

### Opportunities & Risks

The renewable transportation fuels market is a rapidly growing market which looks to be continuing to grow. In the past month, the Environmental Protection Agency announced it would boost renewable fuel production via its Final Requirements for the Renewable Fuel Standard, effectively guaranteeing demand for such fuels for the next several years (EPA, 2015). With California’s Low Carbon Fuel Standard being upheld after several attempts to repeal it, the state is also ensuring a market for renewable fuels for at least the next four years until new legislation takes effect in 2020 (Hull, 2013). With both of these programs showing no signs of slowing down, there is significant opportunity for the SFPUC to maximize the value of its assets and enter the transportation fuel market.

There are inherent risks associated with any business model that relies on subsidies in order to be profitable. With the delivery cost of each GGE being higher than the commodity price of CNG, reductions or outright disappearance of subsidies would threaten the viability of a renewable transportation fuel scenario at the SFPUC. This is an unlikely worst-case scenario that is not expected to occur. There are also risks associated with having stranded assets should the program be unsuccessful or ended prematurely. By investing a large sum of capital into any project, the SFPUC does not want to be left with unused or underutilized assets that do not promote public good.

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## Appendix 1 - Glossary of Terms

**Anaerobic Digester** - A piece of equipment used in the process of breaking down organic matter in the absence of oxygen whose byproduct is biogas

**BTU** - British Thermal Unit: The amount of work needed to raise the temperature of 1 pound of water by 1 degree Fahrenheit

**$CO_2$e** - Carbon dioxide equivalent: A standard unit for measuring carbon footprints incorporating several greenhouse gases and equating them to the global warming potential of carbon dioxide

**Conditioning Skid** - A piece of equipment used to remove liquid and solid contaminants such as water, siloxanes and hydrogen sulfide from biogas in the process of conditioning it into biogas

**GGE** - Gas Gallon Equivalent: The amount of alternative fuel it takes to equal the energy content of one liquid gallon of gasoline

**HHV** - High Heating Value: the amount of energy contained in one standard cubic foot of gas

**kWh** - Kilowatt hour: One kilowatt of power sustained for one hour

**LCFS -** Low Carbon Fuel Standard: A rule enacted to reduce carbon intensity in transportation fuels as compared to conventional petroleum fuels, such as gasoline and diesel

**Membrane -** A piece of equipment used to strip $CO_2$ from biogas in the process of conditioning it into biomethane

**MJ** - Megajoule: 1,000,000 joules of energy

**MW** - Megawatt: 1,000 kilowatts of power

**RIN** - Renewable Identification Number: A serial number assigned to each unit of renewable fuel as it is introduced into U.S. commerce. A RIN credit is produced when a gallon of renewable fuel is produced. RIN credits can be sold on the open market

**SCF** - Standard Cubic Feet: The amount of natural gas contained at standard temperature and pressure in a cube whose edges are one foot long

**SCFM** - Standard Cubic Feet Per Minute: The volumetric flow rate of a gas corrected to "standardized" conditions of temperature and pressure