# Energy Beet-to-Ethanol Fuel Pathway under the Low Carbon Fuel Standard

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*December, 2015*

## Pathway Summary

This fuel pathway document presents the carbon intensity (CI) for the production of Tracy Renewable Energy's (TRE) ethanol fuel from energy beets grown in Tracy, California. Energy beets are similar to sugar beets but have higher fermentable sugar content. The fuel pathway includes energy beet cultivation, beet transport, beet processing, ethanol and co-product production, ethanol transport and distribution and fuel combustion. The direct field-to-wheels (FTW) CI of this pathway is -16.36 grams of carbon dioxide-equivalent greenhouse gas emissions per megajoule of ethanol (g $CO_2$e/MJ ethanol). Including the indirect land use change (iLUC) emissions associated with energy beets grown in California (30 g $CO_2$e/MJ ethanol) yields total (direct + indirect) emissions of 13.64 g $CO_2$e/MJ ethanol.

TRE's ethanol plant is co-located with a wastewater treatment plant (WWTP), desalination plant and an anaerobic digester. The desalination plant enables the City of Tracy to meet water quality objectives for its municipal wastewater discharge to the Sacramento-San Joaquin Delta. The primary objectives of the desalination plant are to remove salt from the municipal discharge to reduce the total salinity load (tons of salt discharged) and to return clean water to the City to reduce the salt concentration of the remaining untreated wastewater streams. The desalination plant utilizes a distillation process incorporating a natural gas boiler and a novel technology termed a Steamboy® to remove salt from the water. The desalination process produces residual energy in the form of steam, which is used to generate electricity used in the desalination plant, ethanol plant and anaerobic digester.

The anaerobic digester produces digester gas (biomethane) from greenwaste, manure and glycerin, which is combusted in a boiler to provide process steam to the ethanol plant. The ethanol plant processes locally grown energy beets into anhydrous ethanol and dried beet pulp. The dried beet pulp is sold to the local dairy industry as animal feed displacing feed corn.

This fuel pathway differs from existing LCFS pathways in two key ways: the energy beet feedstock has not been previously evaluated by ARB and TRE's fuel pathway is the first liquid fuel pathway based on digester gas process fuel under the LCFS. Due to these novelties, the proposed fuel pathway requires a Method 2b pathway application. Energy beet farming data was provided by TRE's feedstock supplier and is based on demonstration plots of Roundup Ready® beets grown in Tracy, CA. The Roundup Ready® beet seeds used provide many improvements over conventional beet seeds, significantly reducing cultivation fuel and chemical use.

The California GREET model (CA-GREET) was customized to represent TRE's energy beet fuel pathway for this analysis. The CA-GREET model is a California-specific version of the


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Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET)[1] model developed by Argonne National Laboratory. The results obtained from the California-modified GREET model (v1.8b, released December 2009) are reported in this document.

## Pathway Configuration

The pathway diagram presented in Figure 1 below summarizes TRE's energy beet-to-ethanol fuel pathway. The diagram shows the desalination plant outside of the system boundaries because the fuel pathway is only based on the ethanol plant; however, the diagram shows that residual steam energy produced from the CST is used to generate electricity in the power plant using a condensing turbine and this electricity is used to operate the power plant, desalination plant, anaerobic digester and ethanol plant.

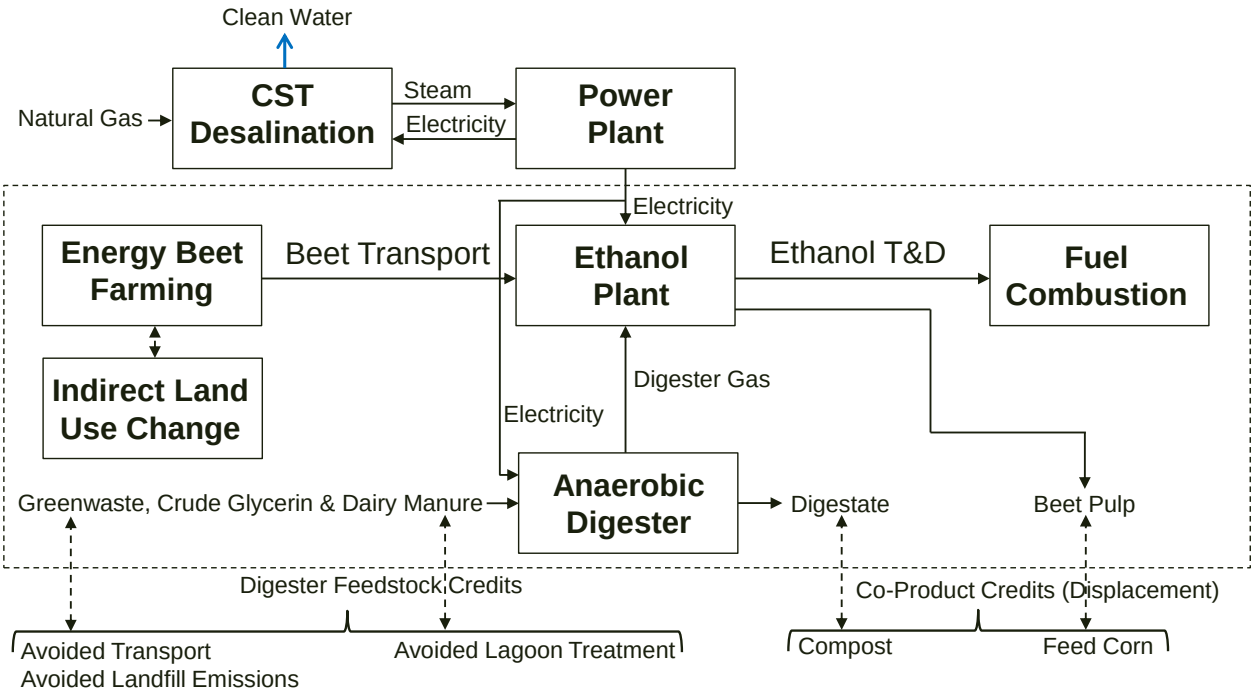


**Figure 1.** TRE's Energy Beet-to-Ethanol Fuel Pathway

## Project Purpose

The primary purpose of this project is to construct and operate a desalination plant in the City of Tracy. The desalination plant will process approximately XXX thousand gallons per day (gpd) of treated effluent generated by the Tracy WWTP to a quality suitable for discharge into the Sacramento-San Joaquin River Delta meeting State Water Quality Objectives for water quality discharge. The ethanol plant will also produce approximately XXX thousand gpd of filtered waste water produced from beet water content, which will be combined with the desalinated water for a total of XXX million gpd of cleaned water discharged into the delta.

[1]Argonne National Laboratory (2008). The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model. http://greet.es.anl.gov/main

The Tracy WWTP currently processes approximately 9 million gpd of effluent and discharges this treated effluent directly into the Delta. The WWTP's discharge currently contains salt concentrations that exceed the Delta salinity standards. Salinity in water is generally measured as Electrical Conductivity (EC). The treated desalination water will be blended back into the remaining WWTP effluent prior to discharge into the Delta. The newly blended and treated effluent will have lower salinity and will assist the City in compliance with all applicable Delta salinity standards. Project implementation will effectively reduce salinity loading of the discharge by 10%.

Large-scale reverse osmosis has been determined by the State Water Resources Control Board (SWRCB) to be an impractical approach to reducing the salinity of municipal waste (SWRCB Order WQ 2005-0005, City of Manteca). The WWTP requires distillation-based desalination, necessitating the use of process fuel to purify the water. TRE's plant will burn natural gas as the process fuel for project operations. The desalination plant will consume approximately XXX MW in the process of cleaning the water plus XXX MW electrical power. This represents the baseline energy requirement to separate the water and salt. By utilizing a condensing turbine to self-generate the required electrical power, XXX MW of total power is generated, providing the ethanol plant with XXX MW.

The core of the desalination technology is the Combined Solar Technologies (CST) SteamBoy® system, which is an economically viable and commercially available solution to the salinity problem at the City's WWTP. The CST SteamBoy® process will intercept the effluent from the WWTP before it reaches the Delta and process it to near potable standards. The Plant will be similar to a typical distillation-based desalination facility, except that the SteamBoy® steam generator system permits the use of the WWTP effluent as feed water. The SteamBoy® effectively functions as a closed-loop, shell and tube heat exchanger with the conventional natural gas boiler. The natural gas boiler provides clean steam to the SteamBoy®, which transfers heat from the clean steam to the saline wastewater. This innovation provides significant advantages over current desalination systems. The system purifies wastewater without the usual fouling associated with conventional boilers and yields high quality steam as a byproduct for other purposes. The system also represents a significant innovation in electricity generation: whereas conventional electricity generation or process heat plants consume large amounts of clean water for the production of electricity, the proposed plant will produce large amounts of clean water in the process of making electricity.

The desalination process will produce salt extracted from the treated effluent as a co-product. The WWTP will generate up to XXX tons per year of solid salt. The salt will be added to the animal feed that is generated from the sugar beet to ethanol process. The salt is not considered an ethanol co-product and does not receive a credit under this fuel pathway.

## Ethanol Plant Process Steam and Electricity

As discussed above, the purpose of the project is water desalination. Ethanol and electricity production have been identified as the two most promising uses for residual energy resulting from desalination to reduce the net cost to City ratepayers. The City of Tracy requires water desalination by distillation to meet water quality standards for discharge into the delta; since

distillation is required, the process generates XXX psi steam which is directed to a condensing turbine for electricity generation. The turbine generates XXX of electricity and the ethanol plant requires XXX of this power, or XXX. In the life cycle assessment, this electricity is modeled as electricity derived from a utility boiler and steam turbine, based on the default efficiency from CA-GREET. Table 1 below summarizes the electricity input for ethanol production.

**Table 1.** Ethanol Plant Electricity Consumption

| Parameter | Power (MW) | Electricity (MWh) | Electricity Rate (kWh/gal EtOH) |
|---|---|---|---|
| Ethanol Plant | XXX | XXX | XXX |

The process steam used by the ethanol plant is derived from digester gas (DG), produced from greenwaste, dairy manure and crude glycerin. The digester feedstocks are converted to DG (biomethane) and digestate in an anaerobic digester onsite and burned in a boiler system dedicated to digester gas and separate from the natural gas boiler system in the desalination plant.

There are 12 components of the life cycle treatment of the digester gas:

1. Digester feedstocks, DG production and fuel properties
2. Digester feedstock transport
3. Digester gas flaring emissions
4. Digester fugitive emissions
5. Use of DG to operate the ethanol plant
6. Natural gas-based electricity to operate digester
7. Digester loading and unloading
8. Digestate composting emissions
9. Glycerin upstream emissions
10. Credit for avoided landfilling, flaring and composting emissions
11. Credit for avoided manure management emissions
12. Credit for digestate

## 1. Digester Feedstocks, DG Production and Fuel Properties

TRE uses greenwaste, dairy cow manure and crude glycerin as feedstocks for the anaerobic digester. The digester feedstock mix will vary slightly over time and TRE expects to process XXX thousand tons of greenwaste (wet basis), XXX thousand tons of dairy manure (wet basis) and up to XXX tons glycerin per year, according to the operational conditions imposed on TRE under this fuel pathway. The digester can process up to XXX thousand tons of feedstock (wet basis) per year. The digester feedstock mix modeled in this fuel pathway is summarized below in Table 2; the DG produced from each feedstock is derived from the DG production rates in Table 3. Since emission credits are associated with greenwaste diverted from a landfill and manure diverted from anaerobic lagoons, this fuel pathway is conservatively based on the minimum of the expected range for both of these feedstocks (XXX thousand tons of greenwaste and XXX thousand tons of manure per year). The remaining digester feedstock needed to meet the ethanol plant's process steam needs is assumed to be glycerin (XXX tons of glycerin per year). The

upstream emission impact assessed for use of glycerin is calculated using CA-GREET's biodiesel pathway; no credit is associated with glycerin use. TRE has agreed to operational conditions under their LCFS fuel pathway pertaining to the quantity of each digester feedstock used to ensure that TRE's ethanol never exceeds the CI summarized in this fuel pathway document.

**Table 2.** Digester Feedstock Mix

| Waste Feedstock | Wet ton/yr | Dry tons/yr | Wet Tonne/yr | mmBtu DG/yr | Share |
|---|---|---|---|---|---|
| Pre-processed greenwaste | XXX | XXX | XXX | XXX | XXX |
| Dairy Manure | XXX | XXX | XXX | XXX | XXX |
| Glycerin | XXX | XXX | XXX | XXX | XXX |
| Total Digester Feedstock | XXX | XXX | XXX | XXX | XXX |

DG production is modeled based on DG production rates guaranteed by TRE's digester equipment supplier. Table 3 below summarizes the DG production rates by feedstock and relevant data needed to conduct the life cycle analysis of the digester. The effective heating value of the DG produced is XXX Btu/scf.

**Table 3.** DG Production Rates and Characteristics

| Digester Feed Type | Biogas scf/ton | % $CH_4$ | Methane scf/wet ton | Methane Btu/wet ton | Methane Btu/Dry ton |
|---|---|---|---|---|---|
| Pre-processed greenwaste | XXX | XXX | XXX | XXX | XXX |
| Dairy Manure | XXX | XXX | XXX | XXX | XXX |
| Glycerin | XXX | XXX | XXX | XXX | XXX |
| Weighted Average | XXX | XXX | XXX | XXX | XXX |

## 2. Digester Feedstock Transport

The greenwaste is collected by a heavy-duty truck in San Jose and transported approximately 60.1 miles to the ethanol plant in Tracy, California. Absent TRE, the greenwaste would be trucked 78.8 miles from San Jose to Forward Landfill in Stockton, California. Therefore, utilizing the greenwaste in TRE's digester avoids 18.7 miles (each way) of heavy-duty truck transport; the emissions associated with the avoided transport are credited to TRE's ethanol. The credit is calculated using the CA-GREET model based on 18.7 miles of heavy-duty truck transport (each way) of herbaceous biomass. The dairy manure is collected from 3 nearby dairy farms with a maximum distance of 10 miles from TRE. The avoided fate for the dairy manure is treatment onsite in an anaerobic lagoon, so no avoided truck transport is counted for the manure. The crude glycerin is produced by 2 nearby biodiesel facilities, located approximately 15 miles from TRE and adjacent to TRE, respectively. Although the biodiesel plants consider the crude glycerin a waste product and would have it trucked to a landfill absent TRE, no avoided glycerin transport is assumed in this fuel pathway.

The overall digester feedstock transport emissions are calculated based on the net transport distance for all of the digester feedstocks, as indicated in Table 4 below. The greenwaste hauled (XXX tons/year) is based on processing XXX tons of digestible greenwaste after XXX% of the

indigestible woody material has been removed. As the table shows, the overall net transport distance avoided by heavy-duty truck is 15.5 miles.

**Table 4.** Anaerobic Digester Feedstock Net Transport

| | Greenwaste | Cow Manure | Glycerin 1 | Glycerin 2 | |
|---|---|---|---|---|---|
| Transport to TRE | 60.1 | 10 | 15 | 0.06 | mi |
| Avoided Transport to Landfill | 78.8 | 0.0 | 0.0 | 0.0 | mi |
| Net Transport by Feedstock | -18.7 | 10.0 | 15.0 | 0.06 | mi |
| Feedstock transported | XXX | XXX | XXX | XXX | ton |
| Share of Digester Feedstock | XXX | XXX | XXX | XXX | % |
| Overall Net Transport | -15.5 | mi | | | |

Energy use and emission results were calculated in CA-GREET for the net avoided greenwaste transport distance of 15.5 miles by heavy-duty truck and the results are XXX g $CO_2$e/ton feedstock or -0.58 g $CO_2$e/MJ ethanol.

### 3. Digester Gas Flaring Emissions

TRE's DG requires minimal gas clean up and is stored in a storage balloon located adjacent to the digester vessels. The storage balloon can hold up to two days' worth of DG and TRE can always use the stored DG to desalinate water in the adjacent desalination plant if the ethanol plant goes offline; TRE seeks to utilize as much of the DG as possible and minimize flaring. Therefore, TRE expects very little gas flaring. However, following a conservative life cycle approach, this fuel pathway assumes that the emergency flare will be operated for approximately 5 days per year, 4 hours each day. Since the emergency flare's DG combustion rate is not known and no flare combustion rates are listed in TRE's air permit, this analysis uses the simplifying assumption that the digester gas production rate is equal to the flare's DG combustion rate. Since the flare burns DG at a much lower rate than the DG produces gas, this assumption is conservative. Since the digester will produce DG all of the time, this assumption leads to a flare rate of 0.23% of produced gas flared:

$$\text{DG Flare Rate} = \left( \frac{(5 \text{ days flaring/year})(4 \text{ hours flaring/day})}{(365 \text{ days DG Production/year})(24 \text{ hours DG production/day})} \right) = 0.23\%$$

Based on TRE's produced gas usage rate of XXX Btu DG/gal, the flared DG is as follows:

$$\text{DG Flared} = (\text{XXX Btu DG/gal})(0.23\% \text{ DG flared/DG used}) = \text{XXX Btu DG flared/gal}$$

Flaring results in combustion carbon dioxide ($CO_2$), "pass through" $CO_2$, combustion nitrous oxide ($N_2O$) emissions and uncombusted methane ($CH_4$) emissions; the methane emissions are calculated in this section but are counted as fugitive emissions in the next section.

Combustion $CO_2$ emissions are calculated based on the flare destruction efficiency assumed in the LCFS HSAD fuel pathway (99.77%):

$$\text{Combustion DG} = (\text{XXX Btu DG flared/gal})(0.23\% \text{ DG flared/DG used}) = \text{XXX Btu DG/gal}$$

$$\text{Combustion } CO_2 = (\text{XXX Btu } CH_4\text{/gal}) / (962 \text{ Btu/scf } CH_4) * (20.25 \text{ g/scf } CH_4) * \left(\frac{44 \text{ g/mol } CO_2}{16 \text{ g/mol } CH_4}\right) / (80.5 \text{ MJ/gal}) = \text{XXX g } CO_2\text{/MJ ethanol}$$

The fuel properties for methane gas are used in the above equation because methane is assumed to be the only component of DG that contributes to its heating value. This result is equivalent to XXX g $CO_2$/mmBtu DG.

The "pass through" $CO_2$ emissions are calculated as follows:

$$\text{"Pass Through" } CO_2 = (\text{XXX Btu DG flared/gal}) / (\text{XXX Btu/scf DG}) * \left(1 - \frac{\text{XXX scf } CH_4}{\text{scf DG}}\right) * \left(\frac{55.98 \text{ g } CO_2}{\text{scf } CO_2}\right) / (80.5 \text{ MJ/gal}) = \text{XXX g } CO_2\text{/MJ ethanol}$$

The "pass through" $CO_2$ emissions are calculated based on the DG heating value (XXX Btu/scf DG) calculated in the subsection 1 of this section. This result is equivalent to XXX g $CO_2$/mmBtu DG.

Flare $N_2O$ emissions are calculated based on the flare $N_2O$ factor used in the LCFS HSAD pathway. ARB's HSAD spreadsheet was modified to reflect DG with XXX% methane content instead of 65%, which yields annual $N_2O$ emissions of 11,710,990 g $N_2O$/year resulting from flaring of 35.3 scfm $CH_4$. These factors result in an emission factor of 655.9 g $N_2O$/mmBtu biogas flared. The $N_2O$ emissions are calculated from this factor as follows:

$$\text{Flare } N_2O = (655.9 \text{ g } N_2O\text{/mmBtu DG})(\text{XXX Btu DG/gal})\left(\frac{\text{mmBtu}}{10^6 \text{ Btu}}\right)(298) / (80.5 \text{ MJ/gal}) = \text{XXX g } CO_2\text{e/MJ ethanol}$$

This result is equivalent to XXX g $CO_2$/mmBtu DG.

The uncombusted $CH_4$ emissions that pass through the flare are calculated based on the DG flared and the flare destruction efficiency:

$$\text{Flare } CH_4 = (\text{XXX Btu DG flared/gal})(1 - 99.77\%) / (962 \text{ Btu/scf } CH_4) = 0.0001 \text{ scf } CH_4\text{/gal}$$

$$(0.0001 \text{ scf } CH_4\text{/gal})(20.8 \text{ MGY}) / (315 \text{ days/year}) / (24 \text{ hours/day}) / (60 \text{ min/days}) = 0.01 \text{ scfm } CH_4$$

This flared methane emission rate is counted in the next section as a fugitive emission.

## 4. Digester Fugitive Emissions

The anaerobic digester remains a closed system throughout the project duration and no fugitive emissions from the digester are expected. However, this fuel pathway conservatively follows the fugitive assumptions used by ARB in the High Solids Anaerobic Digestion (HSAD) fuel pathway. The HSAD pathway includes two sources of fugitive methane emissions, from the gas compressor located between the digester and gas purification unit and from a second compressor that compresses the purified gas to pipeline pressure. Since TRE uses only one compressor to compress the biogas to XXX psig, the fugitive biomethane emissions for TRE's fuel pathway are based on the fugitives for the first compressor (5.5 scfm $CH_4$) in the HSAD pathway.

The second source of biomethane fugitive emissions includes uncombusted methane (0.01 scfm $CH_4$) from flared biogas, discussed above. Therefore, the total methane fugitive emissions are 5.5 scfm $CH_4$ (due to rounding) and the fugitive emission rate can be calculated as following, based on the net methane production rate in the LCFS HSAD pathway (396.7 scfm $CH_4$):

$$\left(\frac{5.5\text{ scfm CH}_4\text{ fugitives}}{396.7\text{ scfm CH}_4\text{ produced}}\right)=1.39\%$$

Finally, the GREET model used under the LCFS includes a 0.01 $m^3$ $CH_4/m^3$ DG fugitive factor for feedstock handling and digester leakage, equivalent to 0.0182 $m^3$ $CH_4/m^3$ $CH_4$ based on XXX% DG methane content. Adding this fugitive emission rate for compressor losses and flaring yields a total fugitive rate of XXX $m^3$ $CH_4/m^3$ produced (XXX%). This rate is combined with the ethanol plant's heat rate to determine total fugitive emissions:

$$\text{Fugitive CH}_4=\left(\text{XXX }\frac{\text{Btu CH}_4}{\text{gal EtOH}}\right)\left(\frac{\text{scf CH}_4}{962\text{ Btu CH}_4}\right)\left(\frac{20.25\text{ g CH}_4}{\text{scf CH}_4}\right)(3.21\%)(25)/(80.5\text{ MJ/gal})$$

$$=\text{XXX }\frac{\text{g CO}_2\text{e}}{\text{MJ EtOH}}$$

This result is equivalent to XXX g $CO_2$e/mmBtu DG.

## 5. Use of Digester Gas to Operate the Ethanol Plant

DG is used to produce steam in the ethanol plant and DG fugitive and flaring emissions must be accounted for to determine the quantity of digester feedstock needed for this fuel pathway. Table 5 below summarizes the DG balance and feedstock rate needed to produce the DG (based on the feedstock mix outlined in subsection 1). As the table shows, the fuel pathway requires a total of XXX Btu DG/gallon ethanol or XXX wet tonne feedstock/gallon ethanol. The feedstock use rate for each of the digester feedstocks is used to determine the upstream emissions and credits associated with DG use. The emissions associated with the DG combusted for process steam (XXX Btu/gal) are based on the CA-GREET emissions factors for a small utility boiler. The "pass through" carbon dioxide emissions associated with DG combustion are based on the methane content (XXX%) of the DG.

**Table 5.** DG Requirement

| DG Fate | % Net DG | Btu DG/gal | Wet tonne feedstock/gal |
|---|---|---|---|
| Ethanol Plant | | XXX | XXX |
| Fugitive Emissions | 3.21% | XXX | XXX |
| Flaring Emissions | 0.23% | XXX | XXX |
| Total | | XXX | XXX |

## 6. Natural gas-based electricity to operate digester

The electricity used by the ethanol plant is derived from at the power plant adjacent to the ethanol and desalination plants. The desalination plant processes water by distillation, producing high-pressure steam, which is directed through a steam turbine in the power plant to generate electricity. The greenhouse gas emissions associated with electricity use in the ethanol plant is calculated based on a 100% natural gas electricity mix and the CA-GREET default efficiency (34.8%) for a power plant using a natural gas boiler and steam turbine.

## 7. Digester Loading and Unloading

The digesters used are large, cylindrical vessels with a conical base located 10 – 12 feet above the ground. The greenwaste feedstock is delivered from the heavy-duty trucks to the top of the digester using a diesel-powered front-end loader and the digestate produced is removed from the bottom and loaded into a heavy-duty truck for transport to the fields where it is applied as fertilizer. During normal operation, no energy is required to transport the digestate from the digester to the truck; the digestate flows freely from the bottom via gravity.

The front-end loader energy use and emissions are modeled based on the front-end loader modeled in ARB's HSAD fuel pathway. The loader is modeled as a 261 horsepower (hp) loader consumes 17,404 gallons of ultra-low sulfur diesel (ULSD) to move 95,000 tons of greenwaste per year and produce 238,199,913 MJ biomethane/year. Therefore, the ULSD use rate is calculated as follows:

$$\left(\frac{17{,}404 \text{ gallons ULSD}}{\text{year}}\right)\left(\frac{127{,}464 \text{ Btu}}{\text{gallon ULSD}}\right)\left(\frac{\text{year}}{238{,}199{,}913 \text{ MJ}}\right)\left(\frac{1055.056 \text{ J}}{\text{Btu}}\right) =$$

$$9{,}826 \ \frac{\text{Btu ULSD}}{\text{mmBtu biomethane}} \text{ or } 23{,}352 \text{ Btu diesel/wet ton digester feedstock}$$

The fuel cycle emissions associated with ULSD use include combustion emissions and upstream production emissions. As in the HSAD fuel pathway, the loader's combustion emissions are modeled based on farm tractor emission factors. The diesel tractor emission factors and the ULSD fuel cycle emissions are derived from the CA-GREET model (Table 6 below).

**Table 6.** Fuel Cycle Greenhouse Gas Emissions for ULSD Used in a Farm Tractor (g/mmBtu)

| Emission | Diesel Tractor Emission Factors | ULSD Fuel Cycle Emissions | Total |
|---|---|---|---|
| VOC | 9.80 | 107.69 | 117.49 |
| CO | 26.88 | 402.58 | 429.46 |
| $CH_4$ | 101.29 | 9.72 | 111.01 |
| $N_2O$ | 0.23 | 0.92 | 1.15 |
| $CO_2$ | 18,919 | 77,204.08 | 96,123 |
| **Total GHG** | **21,592** | **78,690** | **100,282** |

Based on the ULSD emissions in Table 6, the ULSD emissions expressed per mmBtu biomethane and per gallon ethanol produced are presented in Table 7. The total emissions associated with the loader are 2,772 g $CO_2$e/gallon, 62.13 g $CO_2$e/gallon ethanol are equivalent to 0.77 g $CO_2$e/MJ ethanol.

**Table 7.** Total ULSD Emissions Associated with Front-End Loader

| Emission | g/mmBtu methane | g/gal Ethanol | g/MJ Ethanol |
|---|---|---|---|
| VOC | 3.25 | 0.07 | 0.001 |
| CO | 11.87 | 0.27 | 0.003 |
| $CH_4$ | 3.07 | 0.07 | 0.001 |
| $N_2O$ | 0.03 | 0.00 | 0.000 |
| $CO_2$ | 2,657 | 59.56 | 0.740 |
| **Total GHG** | **2,772** | **62.13** | **0.77** |

## 8. Digestate Composting Emissions

Although TRE uses or sells the digestate without further composting as a soil amendment and fertilizer, this fuel pathway assumes composting, following the life cycle treatment in the HSAD pathway. The HSAD pathway is based on digesting 86,168 tonne feedstock per year into 72,325 tonne digestate per year (0.84 tonne digestate/tonne feedstock). The HSAD composting emission result is 14,706,483,260 g $CO_2$e/year, equivalent to 203,340 g $CO_2$e/tonne digestate.

TRE will produce approximately XXX tonne digestate/year from XXX tonne/year digester feedstock (based on the HSAD pathway rate of 0.84 tonne digestate/tonne feedstock). Based on the emission rate above, TRE's composting emissions would be:

$$(\text{XXX tonne digestate/year})(203{,}340\ \text{g CO}_2\text{e/year})/(20.8\ \text{MGY})/(80.5\ \text{MJ/gal})$$
$$= \text{XXX g CO}_2\text{e/MJ}$$

The composting emission result is equivalent to XXX g $CO_2$e/mmBtu DG.

## 9. Glycerin Emissions

TRE digests up to XXX tons crude glycerin per year sourced from local biodiesel plants. This value was established as an operational limit of glycerin use under this fuel pathway. The greenwaste and manure digester inputs were set to maximize the net CI (emissions plus credits) within the expected ranges of each feedstock. Assuming a minimum quantity of greenwaste and manure is a conservative life cycle assumption that minimizes the greenwaste and manure credits and overall emissions associated with these feedstocks (discussed next).

Upstream glycerin emission results were calculated in CA-GREET after setting the model to the "CA-Marginal" region, to reflect biodiesel plants based in Tracy, CA. Following the LCFS methodology for biodiesel, the analysis uses a hybrid mass/energy allocation method to allocate the biodiesel results between soy meal, biodiesel and glycerin. The allocated emission result, documented in a separate spreadsheet file provided to ARB, is 115.8 g $CO_2$e/lb glycerin or 255,377 g $CO_2$e/tonne glycerin. TRE's upstream glycerin emissions are as follows:

$$\left(255{,}377\text{ g CO}_2\text{e/tonne glycerin}\right)\left(\text{XXX tonne glycerin/year}\right)/\left(20.8\text{ MGY}\right)/\left(80.5\text{ MJ/gal}\right)$$
$$= \text{XXX g CO}_2\text{e/MJ}$$

The glycerin CI is equivalent to XXX g $CO_2$e/mmBtu DG.

## 10. Credit for Avoided Landfill Gas Emissions

The credit for avoided landfilling, flaring and composting emissions assumes the minimum of the expected range in greenwaste use (XXX thousand tons/year) and is based on ARB's treatment of avoided landfill emissions from biomethane production, as outlined in Section VIII of the HSAD pathway document. The TRE digester credit is based on the greenwaste portion of the ARB biomethane pathway.

The ARB fuel pathway assumes that 75% of the methane generated in a landfill is captured and flared and 25% of the methane escapes. Approximately 10% of the escaped methane is oxidized to carbon dioxide and the remaining 90% of the escaped methane enters the atmosphere as fugitive methane. The collected landfill gas is destroyed by a flare with 99.7% destruction efficiency and approximately 1% of gas escapes the flare. The net emission credit for diverting greenwaste from landfilling is 554,281 g $CO_2$e/wet tonne greenwaste (Table VIII-2, page 52 of the pathway document). This emission credit can be calculated based on the total greenwaste usage rate calculated above (XXX wet tonne waste/gal ethanol):

$$\left(\frac{-554{,}281\text{ g CO}_2\text{e}}{\text{wet tonne waste}}\right)\left(\frac{\text{XXX wet ton waste}}{\text{gallon ethanol}}\right)\left(\frac{\text{tonne}}{1.10231\text{ ton}}\right) = \text{XXX}\ \frac{\text{g CO}_2\text{e}}{\text{gallon ethanol}}$$

$$\left(\text{XXX}\ \frac{\text{g CO}_2\text{e}}{\text{gallon ethanol}}\right)\left(\frac{\text{gal}}{76{,}330\text{ Btu}}\right)\left(\frac{1{,}000{,}000\text{ Btu}}{\text{mmBtu}}\right)\left(\frac{\text{Btu}}{1055.056\text{ J}}\right) = \text{XXX}\ \frac{\text{g CO}_2\text{e}}{\text{MJ ethanol}}$$

ARB's results for avoided landfill gas emissions lead to a credit for TRE's ethanol of XXX g $CO_2e$/MJ ethanol (-XXX g $CO_2e$/mmBtu biogas) for the greenwaste processed into biogas and diverted from a landfill.

**11. Credit for Avoided Manure Management Emissions**

TRE receives an emission credit for the fate avoided by the dairy cow manure digested to DG. TRE receives manure from 3 dairies located within 10 miles of TRE's facility. Similar to the greenwaste credit, the manure credit is based on the minimum of the expected range of manure used (XXX thousand tons/year).

All of the dairies use an anaerobic lagoon for manure management. The methodology for calculating avoided manure emissions used for the California greenhouse gas emission inventory is based on the product of the maximum methane-producing capacity for the specific type of animal manure ($B_o$) and the methane conversion factor (MCF) for the manure management system that reflects the percentage of volatile solids actually converted to methane compared to the theoretical maximum ($B_o$). The values of $B_o$ and MCF from the California emission inventory are 0.24 $m^3$ $CH_4$/kg volatile solids (VS) and 0.748 $m^3$ $CH_4$/ $m^3$ $CH_{4Max}$. The avoided manure management methane emissions are calculated as a percentage of the DG yield.

The avoided emissions per kg of VS are as follows:

$$\left(\frac{0.24\ \text{m}^3\ \text{CH}_{4\text{Max}}}{\text{kg VS}}\right)\left(\frac{0.748\ \text{m}^3\ \text{CH}_4}{\text{m}^3\ \text{CH}_{4\text{Max}}}\right)\left(\frac{35.31\ \text{ft}^3}{\text{m}^3}\right)\left(\frac{962\ \text{Btu}}{\text{ft}^3\ \text{CH}_4}\right)=\frac{6{,}098.78\ \text{Btu CH}_4}{\text{kg VS}}$$

TRE's DG yield from dairy manure is:

$$\left(\frac{\text{XXX ft}^3\ \text{DG}}{\text{wet ton manure}}\right)\left(\frac{\text{XXX ft}^3\ \text{CH}_4}{\text{ft}^3\ \text{DG}}\right)\left(\frac{962\ \text{Btu}}{\text{ft}^3\ \text{CH}_4}\right)\left(\frac{\text{wet ton manure}}{\text{XXX ton TS}}\right)\left(\frac{\text{ton TS}}{\text{XXX ton VS}}\right)*$$

$$\left(\frac{1.10231\ \text{ton}}{\text{tonne}}\right)\left(\frac{\text{tonne}}{1{,}000\ \text{kg}}\right)=\frac{\text{XXX Btu CH}_4}{\text{kg VS}}$$

The ratio of avoided emissions to manure DG produced is:

$$\left(\frac{\text{XXX Btu CH}_4\text{/kg VS}}{7{,}844.29\ \text{Btu CH}_4\text{/kg VS}}\right)=\text{XXX\%}$$

This ratio is used to calculate the manure emission credit:

$$-\left(\frac{\text{XXX Btu CH}_4\ \text{avoided}}{\text{Btu CH}_4\ \text{produced}}\right)\left(\frac{\text{ft}^3\ \text{CH}_4}{962\ \text{Btu}}\right)\left(\frac{20.3\ \text{g}}{\text{ft}^3\ \text{CH}_4}\right)\left(\frac{10^6\ \text{Btu}}{\text{mmBtu}}\right)\left(25_{\text{GWP CH}_4}\right)*$$

$$\left(\frac{\text{XXX mmBtu DG}_{\text{manure}}}{\text{year}}\right)\left(\frac{\text{year}}{20.8\ \text{MGY}}\right)\left(\frac{\text{gallon EtOH}}{80.5\ \text{MJ}}\right)=\text{XXX g CO}_2\text{e / MJ}$$

The credit for avoided manure emissions is equivalent to XXX g $CO_2e$/mmBtu manure DG.

**12. Credit for Digestate**

TRE receives an emission credit for the digestate produced, following the factors and methods used in the HSAD pathway and assuming that the digestate is converted to compost. The credit in the HSAD pathway is expressed per unit of digester feedstock (-0.1531 tonne $CO_2$e/tonne digester feedstock). The HSAD fuel pathway assumes that 50% of the compost mass produced displaces mineral fertilizer. Therefore, the digestate credit is:

$$-\left(\frac{0.1531 \text{ tonne } CO_2e}{\text{wet tonne feedstock}}\right)\left(\frac{\text{XXX wet tonne feedstock}}{\text{year}}\right)(50\% \text{ DF})\left(\frac{10^6 \text{ g}}{\text{tonne}}\right)\left(\frac{\text{year}}{20.8 \text{ MGY}}\right)*$$
$$\left(\frac{\text{gallon EtOH}}{80.5 \text{ MJ}}\right) = \text{XXX g } CO_2e / \text{MJ}$$

The digestate credit is equivalent to -XXX g $CO_2$e/mmBtu DG.

## Energy Beet Feedstock

TRE uses Roundup Ready® energy beets as feedstock for ethanol production. Energy beets are very similar to sugar beets, except for a higher quantity of total fermentable sugars and a higher yield per acre. The Roundup Ready® beets reduce the amount of cultivation energy and emissions that are normally required for the traditional varieties of the sugar beet. Energy beets are not grown for food purposes and do not compete directly with food markets. Additionally, the fields in Tracy used to grow the energy beets are much more productive than average, requiring a lower than average nitrogen fertilizer input for beet cultivation.

In the initial phase, Tracy Renewable Energy will process approximately XXX tons of energy beets annually, harvested 6-8 months after planting, from XXX acres. The average yield is approximately 37.8 tons per acre, based on a recent strip trial of 10 beet varieties performed by the University of California, Davis, in Five Points, California.

Agricultural land in the Tracy area was previously used to grow sugar beets, silage corn, alfalfa and tomatoes in annual rotation. After the displacement of sugar beets in the mid-1980s caused by the decline in sugar prices and the increased use of sugar alternatives such as high fructose corn syrup, the land contained approximately 45% silage corn, 45% alfalfa and 10% tomatoes. In the re-established system, the beets will be rotated with the same agricultural system in place. Therefore, the energy beets will not displace any crops, but will resume their traditional place in the historical crop rotation in the Tracy area.

In the second phase, TRE plans to expand beet production to XXX acres, producing approximately XXX tons of beets per year. The second phase will be incorporated into the finalized LCFS fuel pathway, 1-2 years later after the fuel plant has collected process data.

In this life cycle analysis, the farming diesel, herbicide and insecticide inputs are based on data collected for demonstration plots of Roundup® Ready beets grown by Delta Distiller Beets, LLC (DDB), the entity selected by TRE to supply the energy beet feedstock. The beet yield is based

onthe average determined by Dr. Steve Kaffka from trial beet plots conducted in Five Points, CA in 2012 – 2013; this data was provided separately to ARB. The nitrogen fertilizer input is also based on data provided by Dr. Kaffka for sugar beets grown in the Central Valley in California. Phosphate and potash fertilizer inputs are based on Purdue University recommendations because these fertilizers were omitted from the DDB crop trial.

Irrigation water use for sugar beets in the San Joaquin Valley is based on data from Long et al. (1994) and the associated pumping electricity consumption rate is based on data from Klein et al. (2005). These values were combined with the sugar beet yields per acre to determine irrigation electricity use per tonne of beets.

Nitrogen contained in the energy beet residue (tops and leaves) left on the field contribute to nitrous oxide emissions and the residue nitrogen content must be included in the life cycle assessment. Residue N data is based on Frissel (2012); the book indicates a residue yield of 0.026 dry lb residue/lb of beets harvested and a residue nitrogen content of 0.03 lb N/dry lb residue; these values imply a residue nitrogen content of 800 g N/tonne beets harvested.

The energy beet feedstock for the project will be provided by DDB within a 50-mile radius of the project site. Separate feedstock documentation from DDB has been provided to ARB to substantiate the feedstock production inputs.

## Life Cycle Inputs

The life cycle input parameters used to model this fuel pathway are presented in Table 8 below for all steps in the life cycle. The beets are grown in Tracy, CA, and transported by heavy duty truck to the TRE ethanol plant. All of the energy beets are sourced from a radius of no more than 50 miles from the plant; feedstock transport is modeled conservatively based on a 50-mile transport radius rather than based on the weighted average distance. During initial production, the TRE plant will process approximately XXX thousand tons of energy beets annually, producing 20.8 million gallons per year (MGY) of ethanol.

At the ethanol plant, the beets are sliced into small pieces called cossettes and the sucrose is then extracted with water, yielding raw juice and beet pulp. The beet pulp is pressed to extract as much sucrose as possible and the press water produced from pressing is recycled back to the extraction step and combines with the raw juice produced during extraction. The raw juice is then filtered to remove impurities and concentrated prior to fermentation. The sucrose is fermented to hydrous ethanol with yeast and centrifuged to remove the yeast and other solids. Finally, distillation and dehydration are used to remove remaining water from the ethanol, yielding anhydrous fuel (< 1% MC).

Total annual outputs include 20.8 MGY anhydrous ethanol, XXX tons dried beet pulp, XXX tons vinasse (35% moisture content), XXX tons industrial grade carbon dioxide gas, and XXX acre-feet of clean water. The plant also produces approximately XXX thousand gallons of non-specification ethanol and XXX tons of fusel alcohol each year. Fusel alcohols are composed primarily of heavier alcohol molecules and are concentrated in distillation tailings. This fuel pathway does not assign credits for these co-products. The fuel plant includes a regenerative

thermal oxidizer (RTO) fueled by natural gas and used to destroy volatile organic emissions from fermentation. The life cycle assessment of the RTO is based on the emission factors for a natural gas flare.

The undenatured ethanol is transported by heavy duty truck approximately 55 miles to a blending rack where the biofuel is blended with CARBOB. Finally, the fuel is distributed 50 miles by heavy duty truck to refueling stations. Distribution is based on the LCFS default distance for ethanol distribution.

The Supporting Data section in the Appendix of this pathway document summarizes all of the CA-GREET spreadsheet cells that were modified in this analysis.

**Table 8.** Field-to-Plant Gate Input Parameters for TRE Beet-to-Ethanol Fuel Pathway

**Energy Beet Farming**

| **Fuel Inputs (Feedstock Basis)** | | Units |
|---|---|---|
| Diesel Tractor | 16,840 | Btu/tonne |

| **Electricity Input** | | Units |
|---|---|---|
| Grid Electricity (Irrigation) | 41,593 | Btu/tonne |

| **Chemical Inputs** | | Units |
|---|---|---|
| N Fertilizer (Urea) | 2,114.4 | g-N/tonne |
| P Fertilizer ($P_2O_5$) | 198.2 | g-$P_2O_5$/tonne |
| K Fertilizer ($K_2O$) | 330.4 | g-$K_2O$/tonne |
| Herbicide | | |
| Atrazine | 5.4 | g/tonne |
| Metolachlor | 5.4 | g/tonne |
| Acetochlor | 5.4 | g/tonne |
| Cyanazine | 5.4 | g/tonne |
| Insecticide | 20.5 | g/tonne |

| **Residue N Contribution** | | Units |
|---|---|---|
| Tops and Leaves | 800 | g N/tonne |

**Energy Beet Transport**

| **Transport Segment** | Mode | Distance (mi) | Capacity (tonne) |
|---|---|---|---|
| Field to Ethanol Plant | Heavy Duty Truck | 50 | 23 |

## Co-Product Credits

### Dried Beet Pulp

TRE produces dried beet pulp (DBP) at 10% moisture content as a co-product of ethanol production, which will be sold as animal feed into the local dairy market in Tracy, California, displacing silage corn. The DBP is assigned a co-product credit in this fuel pathway using the displacement method, using a displacement factor based on the net energy of lactation ($NE_L$) of silage corn and DBP. Net energy of lactation is the feed energy available for maintenance and milk production after digestive and metabolic losses. Table 9 below summarizes $NE_L$ for both feeds and the calculated displacement factor, determined as a ratio of the DBP and silage corn $NE_L$ values.

**Table 9.** Dried Beet Pulp and Silage Corn Net Energy of Lactation and Displacement Factor

| | DBP | Silage Corn | Units |
|---|---|---|---|
| $NE_L$ | 0.81[1] | 0.72[2] | Mcal/dry lb |
| Assumed Displacement Factor | 1.0 | | lb corn/lb BP |

[1]Beet pulp data is from Shaver et al.
[2]Silage corn data is from Schwab et al. (2003)

The nutrition-based displacement factor derived above implies that 1 pound of DBP displaces 1.13 pounds of feed corn (0.81 Mcal/dry lb/0.72 Mcal/dry lb). This fuel pathway utilizes a conservative displacement factor of 1.0 lb corn/lb DBP. Therefore, the 4.90 lb DBP/gal ethanol (2.22 kg DBP/gal ethanol) produced by TRE displaces 4.90 lb corn/gallon ethanol. The life cycle emission results calculated for corn in CA-GREET are 8,314 g $CO_2$e/bushel (296,936 g $CO_2$e/ton). Accounting for 10% moisture content, the resulting DBP co-product credit is -9.50 g $CO_2$e/MJ ethanol.

## Carbon Intensity Results

The energy beet ethanol life cycle analysis yields direct greenhouse gas results of -16.36 g $CO_2$e/MJ ethanol. Including the indirect land use change (iLUC) emissions associated with energy beets grown in California (30 g $CO_2$e/MJ ethanol) yields total (direct + indirect) emissions of 13.64 g $CO_2$e/MJ ethanol. Table 10 below summarizes the emission results.

As the results demonstrate, chemical use is responsible for more than half of the feedstock production and transport emissions, dominated by nitrogen fertilizer production and use. Feedstock transport emissions (5.14 g $CO_2$e/MJ) are based on transporting the feedstock 50 miles by heavy duty truck. Farming energy emissions (3.31 g $CO_2$e/MJ) include diesel tractor emissions and electricity use for irrigation.

The fuel plant emission results include XXX g $CO_2$e/MJ from the digester front-loader and XXX g $CO_2$e/MJ associated with DG combustion and natural gas-derived electricity use. The natural gas-powered RTO is responsible for XXX g $CO_2$e/MJ. Fugitive and flaring emissions contribute XXX g $CO_2$e/MJ and XXX g $CO_2$e/MJ from digester fugitive emissions, respectively.

**Table 10.** Carbon Intensity Results for Energy Beet Ethanol (g $CO_2$e/MJ)

| Fuel Pathway Step | Beet Ethanol |
|---|---|
| Farming Energy | 3.31 |
| Agricultural Chemicals | 11.92 |
| Feedstock Transport | 5.14 |
| Digester Feedstocks | -84.69 |
| Plant Operation | 46.25 |
| Ethanol Transport & Distribution | 0.91 |
| Denaturant | 0.80 |
| **Direct Field-to-Wheels** | -16.36 |
| **iLUC CI** | 30 |
| **Total Field-to-Wheels** | **13.64** |

Diverting greenwaste from a landfill to TRE for DG production yields a net transport credit of XXX g $CO_2$e/MJ. Avoided landfilling, flaring and composting emissions associated with diverting the greenwaste from the landfill are XXX g $CO_2$e/MJ. Diverting dairy cow manure from treatment in anaerobic lagoons to TRE's digesters yields a credit of XXX g $CO_2$e/MJ. As discussed above, this fuel pathway assumes the digestate produced will be processed into compost even though TRE plans to apply the digestate directly to the beet fields without further composting. This assumption was used because the emissions associated with composting are expected to be similar to those occurring naturally from directly land-applying digestate. The emissions associated with composting are XXX g $CO_2$e/MJ, partially off-set by a digestate credit of XXX g $CO_2$e/MJ. Dried beet pulp receives a co-product credit of XXX g $CO_2$e/MJ for displacing feed corn.

Ethanol transport 55 miles and distribution 50 miles by heavy duty trucks contribute emissions of 0.91 g $CO_2$e/MJ. Ethanol combustion and denaturant emissions under the LCFS are 0.80 g $CO_2$e/MJ. This prospective fuel pathway will be updated based on production data after TRE has begun production. The next section describes the potential implementation of solar power in the TRE ethanol fuel pathway.

## Future Renewable Energy Plans

**Solar Thermal Arrays**

The proposed project includes plans for an alternate thermal heat energy supply that may be implemented in the future. While TRE has not yet determined if solar thermal arrays will be used to supply thermal heat and energy for the proposed project, this future alternative is considered reasonably foreseeable, and is therefore addressed in this document. Approximately 100 acres of land may be used for a solar thermal array system to provide heat and energy for the desalination plant and ethanol plant, located immediately west of the WWTP and south of the fuel storage area. The solar thermal array will be constructed of approximately 4,011 mirrors that direct sunlight and heat to a receiver that would heat the heat transfer oil, which would then be directed to the steam generators to fuel the desalination process. Each mirror would be approximately 17 feet wide and 20 feet long, and would be oriented along 320-foot rows. The maximum mirror height is 10 feet.

## References

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## CA-GREET Life Cycle Inputs

| Pathway Step | Description | Sheet | Cell | Value | Units |
|---|---|---|---|---|---|
| Beet Farming | Residual oil | EtOH | BZ158 | 0 | Btu/tonne |
| | Diesel fuel | EtOH | BZ159 | 16,840 | Btu/tonne |
| | Gasoline | EtOH | BZ160 | 0 | Btu/tonne |
| | Natural gas | EtOH | BZ161 | 0 | Btu/tonne |
| | Coal | EtOH | BZ162 | 0 | Btu/tonne |
| | LPG | EtOH | BZ163 | 0 | Btu/tonne |
| | Biomass | EtOH | BZ164 | 0 | Btu/tonne |
| | Grid electricity | EtOH | BZ165 | 41,593 | Btu/tonne |
| | Nitrogen fertilizer | EtOH | CA144 | 2,114.4 | g/tonne |
| | Phosphate fertilizer | EtOH | CB144 | 198.2 | g/tonne |
| | Potash fertilizer | EtOH | CC144 | 330.4 | g/tonne |
| | Lime fertilizer | EtOH | CD144 | 0 | g/tonne |
| | Herbicide | EtOH | CE144 | 21.5 | g/tonne |
| | Insecticide | EtOH | CF144 | 20.5 | g/tonne |
| | Ammonia N share | Ag_Inputs | H65 | 0% | % |
| | Urea N share | Ag_Inputs | I65 | 100% | % |
| Beet Transport | HD truck distance | T&D_Flowcharts | F1377 | 50 | mi |
| | HD truck capacity | T&D | AE7 | 25 | tons |
| Digester Feedstock Transport | HD truck distance | T&D | FY93 | 1 | mi |
| | HD truck capacity | T&D | AA7 | 25 | tons |
| | HD Truck LCI data | T&D | FY117:FY125 | NA | g/ton*mi |
| Ethanol Plant | Ethanol yield | EtOH | C80 | XXX | gal/tonne |
| | Residual oil | EtOH | CJ158 | 0 | Btu/gal |
| | Diesel fuel | EtOH | CJ159 | 0 | Btu/gal |
| | Gasoline | EtOH | CJ160 | 0 | Btu/gal |
| | Natural gas | EtOH | CJ161 | XXX | Btu/gal |
| | Digester gas[a] | EtOH | CJ162 | XXX | Btu/gal |
| | Coal | EtOH | CJ163 | 0 | Btu/gal |
| | LPG | EtOH | CJ164 | 0 | Btu/gal |
| | Biomass | EtOH | CJ165 | 0 | Btu/gal |
| | Grid electricity | EtOH | CJ166 | 0 | Btu/gal |
| | RTO natural gas | EtOH | CK161 | XXX | Btu/gal |
| Animal Feed Co-Product | DBP yield (0% MC) | EtOH | CN145 | 4.41 | lb/gal |
| | DBP Corn DF | EtOH | CN139 | 1 | lb corn/lb DBP |
| Fertilizer Co-Product | Compost LCI data[b] | Total Emissions Balance | G61 | 0.1531 | tonne $CO_2$e/ton feedstock |
| | Mineral fertilizer DF[b] | Total Emissions Balance | G63 | 0.50 | lb fertilizer/lb compost |
| Fuel Transport | HD truck distance | T&D_Flowcharts | R1427 | 55 | mi |
| | HD truck capacity | T&D | S7 | 25 | tons |
| Fuel Distribution | HD truck distance | T&D_Flowcharts | F1377 | 50 | mi |

[a]Digester gas was added as a new row to CA-GREET and the emissions are calculated based on methane and nitrous oxide emission factors for a natural gas industrial boiler.

[b]The LCI data for displaced mineral fertilizer and the displacement factor are derived from the HSAD pathway spreadsheet; all other entries in the table correspond to CA-GREET inputs.

Process data, inputs, disaggregated results and off-model calculations are available in separate summary spreadsheet. Off-model calculations include emissions due to digester front-loader and emissions and credits associated with use of the anaerobic digester.

# Supporting Data

**Energy Beet Farming**

| **Yield** | | Units |
|---|---|---|
| Energy Beets | 37.8 | ton/acre |

| **Fuel Inputs** | | Units |
|---|---|---|
| Diesel | 4.5 | gal/acre |

| **Chemical Inputs** | | Units |
|---|---|---|
| Nitrogen | 160.0 | lb-N/acre |
| Urea | 160.0 | lb-N/acre |
| $P_2O_5$ | 15.0 | lb/acre |
| $K_2O$ | 25.0 | lb/acre |
| Herbicide | 1.625 | lb/acre |
| Insecticide | 1.550 | lb/acre |

| **Tops and Leaves Left on Field** | | Units |
|---|---|---|
| Yield | 0.026 | dry lb/lb beets |
| N Content | 0.03 | lb N/dry lb tops and leaves |

| **Irrigation Energy** | | Units |
|---|---|---|
| Electricity | 0.860 | MJe/$m^3$ water |
| Irrigation Requirement | 102.05 | $m^3$ water/tonne beets |
| Fraction of Irrigation Requiring Pumping | 50.0% | % |
| Electricity Rate | 12.19 | kWh/tonne beets |

## Disclaimer

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