# CARB METHOD 2 FUEL PATHWAY REPORT

# CORN OIL BIODIESEL

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# EXECUTIVE SUMMARY

In 2009 the California Air Resources Board (ARB/Board) approved the California Low Carbon Fuel Standard (LCFS). The LCFS establishes a compliance schedule that requires fuel providers to reduce the carbon intensity of the fuels they provide each year between 2011 and 2020.

The LCFS requires fuel providers to determine the carbon intensity of the fuels they provide, and to report that information to ARB. ARB uses approved fuel carbon intensities to determine whether providers are in compliance with the regulation. Most transportation fuels sold in California are subject to the provisions of the LCFS.

Fuel providers may use one of two methods to determine the carbon intensities of the transportation fuels they provide to the California market. Under Method 1, fuel providers select carbon intensity values from the fuel carbon intensity lookup table found in the LCFS Regulation. Under Method 2, any entity, whether a regulated party or not, may seek Board or Executive Officer approval of additional fuel pathways or sub-pathways. If a proposed pathway or sub-pathway is approved, it is added to the lookup table, and becomes available to all fuel providers. The use of a new pathway or sub-pathway may begin as soon as it has been added to the lookup table.

Under Method 2A, fuel providers may apply for the addition of new sub-pathways to the lookup table. A sub-pathway is a modified version of a pathway currently present in the table. New sub-pathways are added when a fuel provider can demonstrate that a new or improved fuel production, transport, storage, and/or dispensing process significantly reduces the lifecycle carbon intensity of an existing reference pathway.

The modified pathway that is covered by this application is for an identical concept except that the biodiesel production is located in Ontario Canada. The biodiesel transportation distances have been altered and the carbon intensity of the electric power in Ontario is different than it is in the other regions included in the CA GREET model. In addition the proponent, BIOX, utilizes a slightly different biodiesel production process, which uses more energy than the typical biodiesel plant modelled by CARB. The differences in each stage of the production process are described in more detail in later sections of this report.

The GHG emissions for each stage of the lifecycle for the reference case and for the BIOX case are summarized in the following table.

**Table ES- 1 Lifecycle GHG Emissions**

| Parameter | Base Case | Ontario |
|---|---|---|
| | g/MJ | |
| Corn oil extraction | 12.06 | 12.06 |
| Corn oil transport | 1.37 | 0.98 |
| Biodiesel Production | 4.89 | 9.86 |
| Biodiesel Transport | 0.80 | 3.30 |
| Reduction in DDGS credit | 10.60 | 10.60 |
| Corn oil energy savings | -30.17 | -30.17 |
| Total Tank to Wheel | -0.45 | 6.63 |
| Vehicle Operation | 4.45 | 4.48 |
| Total | 4.00 | 11.11 |

The BIOX pathway emissions are about 178% higher than the reference case due to the increased transportation distances for the feedstock, as well as the product, and higher energy use in the plant. These are partially offset by the lower CI of the electric power in Ontario compared to the US average.

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# 1. INTRODUCTION

In 2009 the California Air Resources Board (ARB/Board) approved the California Low Carbon Fuel Standard (LCFS). The LCFS establishes a compliance schedule that requires fuel providers to reduce the carbon intensity of the fuels they provide each year between 2011 and 2020.

The 2020 carbon intensity level is ten percent below the baseline 2010 level. "Carbon intensity" is the total greenhouse gas emissions from the production, transport, storage, dispensing and use of a fuel. It is expressed as grams of carbon-dioxide-equivalent per megajoule of fuel energy (g $CO_2$e/MJ). In the context of the LCFS, the term "carbon intensity" refers to the full lifecycle greenhouse gas emissions associated with a specific fuel "pathway."

The LCFS requires fuel providers to determine the carbon intensity of the fuels they provide, and to report that information to ARB. ARB uses approved fuel carbon intensities to determine whether providers are in compliance with the regulation. Most transportation fuels sold in California are subject to the provisions of the LCFS.

Regulated parties must report the carbon intensities of the fuels they provide using a table of Board-approved carbon intensity values (a "lookup table"). Carbon intensities outside of the core set developed by staff are the responsibility of fuel providers.

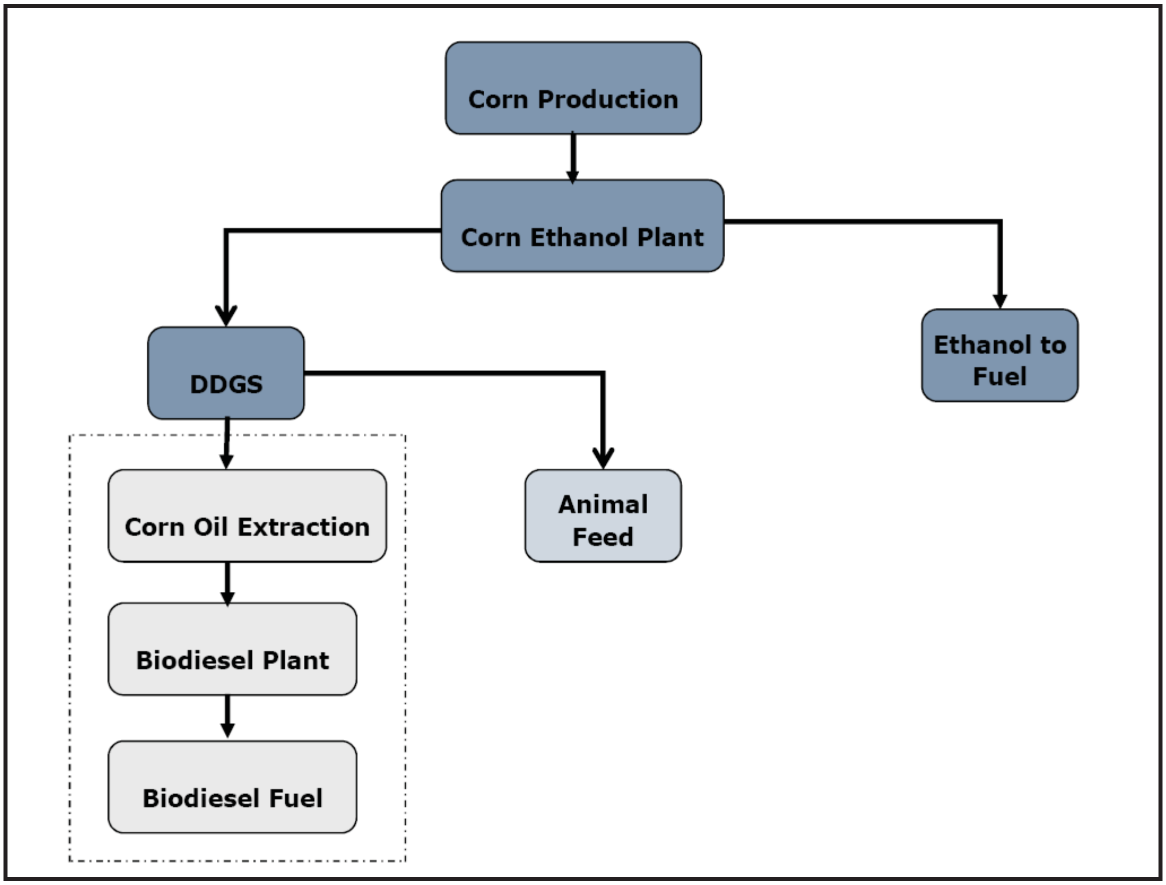
Fuel providers may use one of two methods to determine the carbon intensities of the transportation fuels they provide to the California market. Under Method 1, fuel providers select carbon intensity values from the fuel carbon intensity lookup table found in the LCFS Regulation. Under Method 2, any entity, whether a regulated party or not, may seek Board or Executive Officer approval of additional fuel pathways or sub-pathways. If a proposed pathway or sub-pathway is approved, it is added to the lookup table, and becomes available to all fuel providers. The use of a new pathway or sub-pathway may begin as soon as it has been added to the lookup table.

Under Method 2A, fuel providers may apply for the addition of new sub-pathways to the lookup table. A sub-pathway is a modified version of a pathway currently present in the table. New sub-pathways are added when a fuel provider can demonstrate that a new or improved fuel production, transport, storage, and/or dispensing process significantly reduces the lifecycle carbon intensity of an existing reference pathway.

## 1.1 REFERENCE PATHWAY

CARB published a corn oil to biodiesel pathway in December 2011. This is pathway BIOD007. That pathway was approved by the Board Feb 21, 2012. The components of the pathway are shown in the following figure.

**Figure 1-1 Corn Oil Biodiesel Discrete Components**




The biodiesel production scenario covered by this pathway was for the corn oil extraction to be in the US Midwest and for the biodiesel production to be in California. The calculated well to wheel emissions for the cooking process are shown in the following table.

**Table 1-1 Lifecycle CI Results for Corn Oil Biodiesel – US Production**

| Stage | Emissions, g $CO_2$eq/MJ |
|---|---|
| Corn oil extraction | 12.06 |
| Corn oil transport | 1.37 |
| Biodiesel Production | 4.89 |
| Biodiesel Transport | 0.80 |
| Reduction in DDGS credit | 10.60 |
| Corn oil energy savings | -30.17 |
| Total Tank to Wheel | -0.45 |
| Vehicle Operation | 4.45 |
| Total | 4.00 |

These values were verified using the model ca_greet1.8b_dec09_ARB_corn_oil_092611.xls, with the regional power set to US average.

## 1.2 Modified Pathway Description

The modified pathway that is covered by this application is for an identical concept except that the biodiesel production is located in Ontario, Canada. The biodiesel transportation distances have been altered and the carbon intensity of the electric power in Ontario is different than it is in the other regions included in the CA GREET model. In addition, the proponent, BIOX, utilizes a slightly different biodiesel production process, which uses more energy than the typical biodiesel plant modelled by CARB. The differences in each stage of the production process are described in more detail in later sections of this report.

### 1.2.1 Ontario Power

The marginal power production in the Province of Ontario has been added to the base GREET model that was obtained from CARB. This model is identified as ca_greet1.8b_dec09_ARB_corn_oil_092611.xls.

The average power production in Ontario and the assumed marginal mix is summarized in the following table. The power mix is derived from IEOS, it is updated biannually with the last update Oct 23, 2013. The marginal mix is derived by adding the coal, nuclear and hydro percentages to natural gas. New coal fired electricity production has been effectively banned in Canada as plants will only be approved if the emission intensity is less than 420 kg/MWh, about the same level as an advanced natural gas fired plant. Existing plants will be allowed to continue operation until the end of their economic life. Ontario has an aggressive policy to expand renewable power generation and to exit coal fired power production by 2014.

**Table 1-2 Ontario Power Mix**

| | Average | Marginal |
|---|---|---|
| Residual oil | 0.0% | 0.0% |
| Natural gas | 28.4% | 94.7% |
| Coal | 6.6% | 0.0% |
| Nuclear | 37.0% | 0.0% |
| Biomass | 0.4% | 0.4% |
| Wind | 4.9% | 4.9% |
| Hydro | 22.7% | 0.0% |

The look up table on the Regional LT tab has been modified to include an Ontario average and Ontario marginal option. The marginal power production has a higher carbon intensity than the average power production.

Changes to the model inputs on the BD sheet are highlighted with a light orange background.

# 2. CORN OIL EXTRACTION

Fuel-grade corn oil can be produced at corn ethanol plants by extracting the oil from the stillage portion of the DGS produced at the plants. Extraction follows fermentation and distillation, and precedes DGS drying. Corn Oil extraction systems can be added to existing corn ethanol plants to increase plant energy efficiency and to increase the total volume of fuel that is produced per unit of corn processed. The only allocation of energy and emissions in the biodiesel pathway involve an allocation for glycerine production. The glycerine production is 0.105 lb./lb. of biodiesel (cell C39 on the BD sheet).

The corn oil that is process at the BIOX facility is produced in Ontario and adjacent states.

## 2.1 ENERGY

Electric power and steam are supplied to the corn oil extraction equipment from the ethanol plant's existing power systems. Even though the corn oil extraction equipment consumes energy, plants that produce dry DGS will realize a net energy savings when the extraction equipment is operating. The energy consumption modeled by CARB is summarized in the following table.

**Table 2-1 Corn Oil Extraction Energy**

| Fuel Type | Upstream from the Ethanol Plant | | In-Plant Consumption | Total Energy Use |
|---|---|---|---|---|
| | Fuel Production | Electrical Energy Generation | | |
| Natural Gas (Btu/gal) | 20.34 | N/A | 290 | 310.34 |
| Electricity (Btu/gal) | 978.24 | 33.93 | N/A | 1012.17 |
| Total Energy (BTU/gal) | 998.58 | 33.93 | 290 | 1322.51 |

## 2.2 EMISSIONS

The emissions for the corn oil extraction stage are shown in the following table. The only factor that has changed for the proposed pathway is the electric power mix.

**Table 2-2 Corn Oil Extraction Emissions**

| Parameter | Base Case | US Avg | Ontario |
|---|---|---|---|
| | g/MJ Biodiesel | | |
| VOC | 0.2608 | 0.2608 | 0.2609 |
| CO | 0.0088 | 0.0088 | 0.0047 |
| $CH_4$ | 0.0152 | 0.0152 | 0.0182 |
| $N_2O$ | 0.0001 | 0.0001 | 0.0002 |
| $CO_2$ | 10.82 | 10.82 | 8.74 |
| GHG Emissions | 12.06 | 12.06 | 10.06 |

The total GHG emissions for this stage in Ontario are lower than the reference pathway due to the different electricity CI for Ontario compared to the US average. Since some of the BIOX corn oil feedstock comes from the US, those emissions are used for this pathway.

# 3. CORN OIL TRANSPORT

Generally, the ethanol and the biodiesel plant are not co-located and there are transportation emissions associated with moving the feedstock from one site to the other. The average distance between BIOX and the corn oil suppliers is 190 miles.

## 3.1 DISTANCES

In the CARB scenario, corn oil from Midwest dry mill, dry DGS plants is assumed to be transported 1,400 miles by rail to California rail yards, then 50 miles by heavy duty diesel truck (HDDT) from the destination rail yards to biodiesel production facilities.

BIOX have four corn oil suppliers and the volumes purchased and the distances transported are summarized in the following table. For this pathway we have assumed that the corn oil is shipped 190 miles, slightly higher than the weighted average supply distance, by HHD truck to the biodiesel plant in Ontario.

**Table 3-1 Corn Oil Suppliers**

| Supplier | Purchases, kg | Distance, miles | Kg-mile |
|---|---|---|---|
| IGPC | 3,000,000 | 80 | 3,000,000 |
| GFE | 2,200,000 | 146 | 2,200,000 |
| The Anderson's | 2,000,000 | 290 | 2,000,000 |
| POET | 2,000,000 | 228 | 2,000,000 |
| Total | 9,200,000 | | 3,000,000 |
| Weighted avg. | | 174 | |

## 3.2 EMISSIONS

The emissions for the corn oil transport stage are shown in the following table. The shorter transportation distances result in lower emissions.

**Table 3-2 Corn Oil Transport Emissions**

| Parameter | Base Case | Ontario |
|---|---|---|
| | g/MJ | |
| VOC | 0.0010 | 0.0005 |
| CO | 0.0034 | 0.0014 |
| $CH_4$ | 0.0015 | 0.0010 |
| $N_2O$ | 0.0000 | 0.0000 |
| $CO_2$ | 1.31 | 0.97 |
| GHG Emissions | 1.37 | 0.98 |

# 4. Biodiesel Production

In the reference pathway the biodiesel is produced outside of California. The BIOX process utilizes a co-solvent to speed the reaction process. The co-solvent is recycled as part of the process and the net consumption is very low, less than 0.00075 gal/gal biodiesel. The BIOX process can produce biodiesel from free fatty acids as well as from triglycerides.

## 4.1 Energy

The biodiesel energy consumption in the reference pathway is 2,116 BTU/lb. This includes the process energy and the energy embedded in the chemicals consumed in the process. The breakdown is shown in the following table.

**Table 4-1 Biodiesel Energy Consumption – Reference Case**

| Component | Value | BTU/lb. |
|---|---:|---:|
| Total | 2,116 BTU/lb. | 2,116 |
| Natural gas | 42.0% | 889 |
| Electricity | 2.2% | 47 |
| Methanol | 40.9% | 865 |
| Sodium Hydroxide | 2.0% | 42 |
| Sodium Methoxide | 9.9% | 209 |
| Hydrochloric acid | 3.0% | 63 |

The BIOX process does use higher than normal quantities of natural gas and electric power due to the process design and the fact that the glycerin is upgraded to technical specifications. The quantities of other chemicals, other than the co-solvent are typical for other biodiesel plants. The adjusted GREET model inputs are shown in the following table. There is no provision in the GREET model for additional chemicals to be used but other than methanol the chemicals in the GREET model do not influence the GHG emissions.

The energy consumption is based on data for the period April 1, 2012 to March 31, 2013. During a portion of this period the plant did not operate due to market conditions and the power and energy consumption during this period have been removed from the calculation. The revised biodiesel production energy for modelling is shown in the following table. There is no additional pre-processing energy required for the BIOX process.

**Table 4-2 Biodiesel Energy Consumption – BIOX**

| Component | Value | BTU/lb. |
|---|---:|---:|
| Total | 3,131 BTU/lb. | 3,131 |
| Natural gas | 56.18% | 1,759 |
| Electricity | 6.16% | 193 |
| Methanol | 27.63% | 865 |
| Sodium Hydroxide | 1.34% | 42 |
| Sodium Methoxide | 6.68% | 209 |
| Hydrochloric acid | 2.01% | 63 |

The BIOX process also uses a catalyst, [redacted], that is not included in the GREET model. The carbon footprint of this material is reported to be 5.6 kg $CO_2$eq/kg (Delft University of Technology). At the consumption rate of 0.000745 gal [redacted]/gal of biodiesel this increases the emissions of BIOX biodiesel by 0.11 g $CO_2$eq/MJ. This value has been added to the emissions calculated by the GREET model.

One of the advantages of the BIOX process is higher yield of methyl esters. The feedstock requirement for the reference case is 1.04 lb. of feedstock per lb. of biodiesel produced. The BIOX requirements are 1.0 lb./lb. of feedstock.

## 4.2 EMISSIONS

The emissions for this stage of the lifecycle are shown in the following table.

**Table 4-3 Biodiesel Production Emissions**

| Parameter | Base Case | Ontario |
|---|---|---|
| | g/MJ | |
| VOC | 0.0053 | 0.0071 |
| CO | 0.0054 | 0.0093 |
| $CH_4$ | 0.4069 | 0.6438 |
| $N_2O$ | 0.0103 | 0.0252 |
| $CO_2$ | 4.46 | 9.07 |
| GHG Emissions | 4.89 | 9.75 |
| GHG Emissions (plus THF) | 4.89 | 9.86 |

# 5. Biodiesel Transportation and Distribution

## 5.1 Distances

In the CARB reference case, biodiesel is transported 90 miles by HDDT (100%) to refueling stations.

For this pathway the rail distance is increased to 2,500 miles, the distance from Hamilton, Ontario to Los Angeles. 80% of the Biodiesel is transported by heavy duty truck 50 miles from the plant to bulk terminals; the remaining 20% is distributed directly from the plant. All BD is then transported 90 miles by heavy duty truck from the bulk terminal to refueling stations.

## 5.2 Emissions

The emissions for this stage are shown in the following table for the reference case and the BIOX case.

**Table 5-1 Biodiesel Transportation Emissions**

| Parameter | Base Case | Ontario |
|---|---:|---:|
| | g/MJ | |
| VOC | 0.0012 | 0.0032 |
| CO | 0.0045 | 0.0076 |
| $CH_4$ | 0.0021 | 0.0036 |
| $N_2O$ | 0.0000 | 0.0001 |
| $CO_2$ | 1.88 | 3.17 |
| GHG Emissions | 1.95 | 3.30 |

# 6. DDGS CREDIT

The removal of the corn oil from the dry DGS (DDGS) reduces the DDGS co-product credit for corn ethanol. Because DDGS yields without the use of corn oil extraction are typically 5.34 pounds per gallon of ethanol produced, a reduction of 0.50 pounds per gallon of ethanol represents about a 9.4 percent reduction in the DDGS yield. This 9.4 percent reduction in DDGS yield would translate into a 9.4 percent reduction in the DDGS co-product credit. This reduction in the credit can be considered as an increase in the carbon intensity of corn oil-based biodiesel.

The magnitude of the credit will vary with the carbon intensity of the ethanol production. The values for the reference case and the Ontario case are summarized in the following table. Since some of the corn oil comes from US plants, those emissions are used.

**Table 6-1 Change in DDGS Credit**

| Parameter | Base Case | Ontario |
|---|---|---|
| | g/MJ | |
| VOC | 0.0064 | 0.0064 |
| CO | 0.0574 | 0.0574 |
| $CH_4$ | 0.0066 | 0.0066 |
| $N_2O$ | 0.0158 | 0.0158 |
| $CO_2$ | 5.60 | 5.60 |
| GHG Emissions | 10.60 | 10.60 |

# 7. Non-drying Credit

There are energy savings at the ethanol plant as a result of removing the corn oil. The CARB reference pathway reports this as 3,070 BTU/gal of ethanol. The emission reductions calculated by the model are shown in the following table. These emissions are slightly different when the Ontario marginal power is used. The emission credit is shown in the following table. The base case emissions are used here.

**Table 7-1 Non Drying Credit**

| Parameter | Base Case | Ontario |
|---|---|---|
| | g/MJ | |
| VOC | 0.0116 | 0.0116 |
| CO | 0.0243 | 0.0241 |
| $CH_4$ | 1.4658 | 1.4661 |
| $N_2O$ | 0.0511 | 0.0514 |
| $CO_2$ | 28.61 | 28.58 |
| GHG Emissions | 30.17 | 30.13 |

# 8. COMBUSTION

The final stage of the lifecycle is the use stage. In the CARB framework, the fossil carbon that was in the methanol is oxidized when the fuel is combusted and is accounted for when the biodiesel is burned.

## 8.1 EMISSIONS

The vehicle operation emissions are the same for all biodiesels. These emissions are 4.48 g $CO_2$eq/MJ.

# 9. SUMMARY

The GHG emissions for each stage of the lifecycle for the reference case and for the BIOX case are summarized in the following table.

**Table 9-1 Lifecycle GHG Emissions**

| Parameter | Base Case | Ontario |
|---|---|---|
| | g/MJ | |
| Corn oil extraction | 12.06 | 12.06 |
| Corn oil transport | 1.37 | 0.98 |
| Biodiesel Production | 4.89 | 9.86 |
| Biodiesel Transport | 0.80 | 3.30 |
| Reduction in DDGS credit | 10.60 | 10.60 |
| Corn oil energy savings | -30.17 | -30.17 |
| Total Tank to Wheel | -0.45 | 6.63 |
| Vehicle Operation | 4.45 | 4.48 |
| Total | 4.00 | 11.11 |

The BIOX pathway emissions are about 178% higher than the reference case due to the increased transportation distances for the feedstock, as well as the product, and higher energy use in the plant. These are partially offset by the lower CI of the electric power in Ontario compared to the US average.

# 10. References

CARB. 2011. California-Modified GREET Pathway for the Production of Biodiesel from Corn Oil at Dry Mill Ethanol Plants. http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/15day-cornoil-bd-022112.pdf

Delft University of Technology. 2014. The Model of the Eco-costs / Value Ratio (EVR). http://www.ecocostsvalue.com/EVR/img/Ecocosts2012_LCA_data_on_products_and_services_EI_V2-2%2BIdemat2012.xlsx

IEOS. Ontario Power Mix. http://www.ieso.ca/imoweb/media/md_supply.asp accessed Feb 6, 2014.

# 11. Appendix 1 - GREET Model Changes

| Parameters | Cell Locations | Original GREET values | Company values | Note |
|---|---|---|---|---|
| Electric Power | C83-Regional LT | 2.7% | 0.0% | Ontario Marginal Power |
| | C84-Regional LT | 18.9% | 94.7% | |
| | C85-Regional LT | 50.7% | 0.0% | |
| | C86-Regional LT | 18.7% | 0.0% | |
| | C87-Regional LT | 1.3% | 0.0% | |
| | C88-Regional LT | 7.7% | 4.9% | |
| Corn Oil transport truck | IG93-T&D | 50 | 190 | Transportation distance |
| Corn Oil transport rail | IH93-T&D | 1400 | 0 | |
| Biodiesel Transportation (100% Rail Pathway) | AC 1388-T&D Flowchart | 1200 | 0 | |
| ETOH | C252 to C256 | | See Below | UCO tran for corn oil |
| ETOH | C276 to C280 | | See Below | BD Transport |
| ETOH | B276 to B280 | | See Below | BD Transport |
| Total Energy | B12- BD | 2,116 | 3,131 | BD Processing Energy |
| Yield | B19- BD | 1.11 | 1.00 | |
| NG | M172- BD | 42.0% | 56.2% | |
| Power | M175- BD | 2.2% | 6.2% | |
| Methanol | M177- BD | 40.9% | 27.6% | |
| Sodium Hydroxide | M178- BD | 2.0% | 1.3% | |
| Sodium Methylate | M179- BD | 9.9% | 6.7% | |
| Hydrochloric acid | M180- BD | 3.0% | 2.0% | |
| Rail Transport | F1394-T&D Flowchart | 1400 | 2500 | BD Transport |
| HD Truck Transport | F1398-T&D Flowchart | 50 | 50 | |
| HD Truck Transport | M1390-T&D Flowchart | 90 | 90 | |

C252 = ('T&D'!IG117)/2000/454/BD!C27*Fuel_Specs!E29/Fuel_Specs!B29*1000000
C253 = ('T&D'!IG118)/2000/454/BD!C27*Fuel_Specs!E29/Fuel_Specs!B29*1000000
C254 = ('T&D'!IG123)/2000/454/BD!C27*Fuel_Specs!E29/Fuel_Specs!B29*1000000
C255 = ('T&D'!IG124)/2000/454/BD!C27*Fuel_Specs!E29/Fuel_Specs!B29*1000000

C256 = ('T&D'!IG125)/2000/454/BD!C27*Fuel_Specs!E29/Fuel_Specs!B29*1000000
C276 ='T&D'!CL150+BD!Q212+BD!Q213
C277 ='T&D'!CL151
C278 ='T&D'!CL156
C279 ='T&D'!CL157
C280 ='T&D'!CL158
B276 ='T&D'!CM150
B277 ='T&D'!CM151
B278 ='T&D'!CM156
B279 ='T&D'!CM157
B280 ='T&D'!CM158