## CA-GREET 1.8b versus 2.0 CI Comparison Table

*Approach and Limitations*

The following table compares fuel carbon intensities (CIs) from existing fuel pathways with estimates of corresponding CIs calculated with CA-GREET 2.0. The intent is to illustrate the likely CI changes that would occur as a result of the adoption of CA-GREET 2.0 under the proposed regulation. As such, the following comparisons are not "apples-to-apples": they are not intended to illustrate CA-GREET-driven CI differences for the same production facilities at the same point in time. In most cases, they compare CIs that were certified using CA-GREET 1.8b during the 2010-2015 period with estimated CA-GREET 2.0 CIs for the same fuel groups during the 2016-2020 period. The only departures from this basis of comparison were in the existing (1.8b) corn and sorghum ethanol CIs: these CIs were recalculated to reflect significant differences in plant energy consumption, ethanol and DGS yields, and the DGS-livestock-feed displacement ratio. Staff felt that adjusting for these differences was warranted.

Overall, therefore, the following differences show the effects of time, and of overall improvements in the quality of life cycle inventory data, emission factors, and process efficiency data.

CA-GREET 2.0 is a new life cycle analysis model. It is not a simple CA-GREET 1.8b update. Many of the differences affect individual fuels, but some affect all fuels. The differences in the latter category are the following:

- Emissions from the use of electricity (as both a process and a transportation fuel) are now based on average generation mixes from the U.S. EPA's eGRID database. Marginal mixes were used previously.
- Emission factors for combustion-powered equipment have been updated.
- The contribution of denaturant to the CI of ethanol is now specific to the ethanol pathway. A contribution of 0.8 grams was previously used for all ethanol pathways.
- Natural gas CIs include contributions from conventional and shale gas extraction, and include updated methane leakage rates.
- Fuel transportation modes (pipeline, rail, truck) were updated with new emission factors.
- The CI of Crude Oil production for California fuels is based on the latest OPGEE Model.
- The lower heating values of several fuels (including natural gas) have been updated.
- The use of chemicals and organisms in fuel production (enzymes, yeast, acids and bases, etc.) are now accounted for.

| | Fuel (*source of existing CI in parentheses*) | Existing Regulation | | | | Proposed Regulation | | | | Change g/MJ | Main Drivers of Change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Direct CI, g/MJ | ILUC, g/MJ | Total CI, g/MJ | EER-Adjusted CI, g/MJ | Direct CI, g/MJ | ILUC, g/MJ | Total CI, g/MJ | EER-Adjusted CI, g/MJ | | |
| Baseline Fuels | CARBOB (CBOB001) | 98.38 | | 98.38 | 98.38 | 100.53 | | 100.53 | 100.53 | +2.15 | • OPGEE-derived Crude Oil CI higher (1.3g)<br>• Higher Tailpipe Emissions ($CH_4$ and $N_2O$) (1g) |
| Baseline Fuels | ULSD (ULSD001) | 98.03 | | 98.03 | 98.03 | 102.76 | | 102.76 | 102.76 | +4.73 | • OPGEE-derived Crude Oil CI higher (1.3g)<br>• Higher Refining CI due to lower refining efficiency (3.4g) |
| Baseline Fuels | CaRFG (calculated) | 98.95 | | 98.95 | 98.95 | 99.11 | | 99.11 | 99.11 | +0.16 | • See CARBOB and Ethanol changes |
| North American Natural Gas | North American NG – CNG (CNG002) | 68.00 | | 68.00 | 75.56 | 79.46 | | 79.46 | 88.29 | +12.73 | • Higher Pipeline Energy Intensity (3.8g)<br>• Higher WTT methane leakage (3.7g)<br>• Higher Tailpipe Emission (1.0g) |
| North American Natural Gas | North American NG - LNG (90% liquefaction eff.) (LNG002) | 72.38 | | 72.38 | 80.42 | 86.57 | | 86.57 | 96.19 | +15.77 | • Higher Pipeline Energy Intensity (3.8g)<br>• Higher WTT Methane leakage (3.6g)<br>• Higher Tailpipe Emission (2.8g)<br>• Higher Liquefaction CI (3.4g) |

| | | Existing Regulation | | | | Proposed Regulation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fuel (*source of existing CI in parentheses*)** | | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Change g/MJ** | **Main Drivers of Change** |
| Biomethane | Landfill Gas – CNG (CNG003) | 11.26 | | 11.26 | 12.51 | 19.21 | | 19.21 | 21.34 | +8.83 | • Higher RNG Processing CI (3.6g)<br>• Higher Tailpipe Emission (1g)<br>• Higher Pipeline Energy and Methane Leakage (1.4g)<br>• Larger Flaring Credit (-1.4g) |
| Biomethane | Landfill Gas LNG (90% liquefaction eff.) (LNG007) | 15.56 | | 15.56 | 17.29 | 26.35 | | 26.35 | 29.28 | +11.99 | • Higher Liquefaction CI (3.9g)<br>• Higher RNG Processing CI (3.7g)<br>• Higher LNG Tailpipe Emissions ($CH_4$ and $N_2O$) (2.8g)<br>• Larger Flaring Credit (-1.6g) |
| Biomethane | Dairy and feedlot waste CNG (CNG004) | 13.45 | | 13.45 | 14.94 | 30.13 | | 30.13 | 33.48 | | • Unable to compare due to different production processes |

| | Fuel (*source of existing CI in parentheses*) | Existing Regulation | | | | Proposed Regulation | | | | Change g/MJ | Main Drivers of Change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Direct CI, g/MJ | ILUC, g/MJ | Total CI, g/MJ | EER-Adjusted CI, g/MJ | Direct CI, g/MJ | ILUC, g/MJ | Total CI, g/MJ | EER-Adjusted CI, g/MJ | | |
| Biodiesel | Soybean Biodiesel (BIOD001) | 21.25 | *62.00* | 83.25 | 83.25 | 22.73 | *29.10* | 51.83 | 51.83 | -31.42 | • Higher Biodiesel Production CI due to accounting for chemicals used (2.3g)<br>• Large Difference in Indirect Land Use CI (-33g) |
| Biodiesel | Tallow Biodiesel (BIOD008[1]) | 39.08 | | 39.08 | 39.08 | 32.83 | | 32.83 | 32.83 | -6.25 | • Higher Biodiesel Production CI due to accounting for chemicals used (1.6g)<br>• Lower Rendering Energy (-8g) |
| Biodiesel | UCO Biodiesel (BIOD004) | 18.72 | | 18.72 | 18.72 | 19.87 | | 19.87 | 19.87 | +1.15 | • Higher Biodiesel Production CI due to accounting for chemicals used (1.6g)<br>• Lower BD transport (-0.5g) |
| Biodiesel | Canola Biodiesel (BIOD006) | 31.99 | *31.00* | 62.99 | 62.99 | 35.73 | *14.50* | 50.23 | 50.23 | -12.76 | • Higher Fertilizer Application (5.2g)<br>• Higher Biodiesel Production CI (1.6g)<br>• Large Difference in Indirect Land Use CI (-16.5g) |
| Biodiesel | Corn Oil Biodiesel (from Wet DGS) (BIOD021) | 29.27 | | 29.27 | 29.27 | 28.68 | | 28.68 | 28.68 | -0.59 | • Lower Corn Oil Extraction Energy (-0.9g)<br>• Higher BD production CI (2g)<br>• Lower credit for DGS production (-0.5g) |

[1] For purposes of comparability, the certified CI for North American production was recalculated to reflect California production.

| | | Existing Regulation | | | | Proposed Regulation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fuel (*source of existing CI in parentheses*)** | | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Change g/MJ** | **Main Drivers of Change** |
| Renewable Diesel | Soybean RD (RNWD001) | 20.16 | *62.00* | 82.16 | 82.16 | 22.01 | *29.10* | 51.11 | 51.11 | -31.05 | • Higher Renewable Diesel Production CI (2.2g)<br>• Large difference in Indirect Land Use CI (-33g) |
| Renewable Diesel | Tallow RD (RNWD002) | 39.33 | | 39.33 | 39.33 | 31.22 | | 31.22 | 31.22 | -8.11 | • Lower Rendering Energy (-9.8g)<br>• Higher Renewable Diesel Production CI (1.4g) |
| Renewable Diesel | UCO RD | | | | | 18.21 | | 18.21 | 18.21 | | No Comparison |
| Renewable Diesel | Canola RD | | | | | 30.39 | *14.50* | 44.89 | 44.89 | | No Comparison |
| Renewable Diesel | Corn Oil RD (from Wet DGS) | | | | | 28.49 | | 28.49 | 28.49 | | No Comparison |

| | | Existing Regulation | | | | Proposed Regulation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fuel (*source of existing CI in parentheses*)** | | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Change g/MJ** | **Main Drivers of Change** |
| Sugarcane Ethanol | Sugar cane base Case: no credit (ETHS001) | 27.40 | *46.00* | 73.40 | 73.40 | 41.43 | *11.80* | 53.23 | 53.23 | -20.17 | • Higher Cane Farming Energy (2.9g)<br>• Higher Fertilizer Application (3g)<br>• Higher Straw Burning (2g)<br>• Higher Denaturant (3g)<br>• Higher Ethanol Transport (to CA) emissions (3g)<br>• Lower ILUC (-28.2g) |
| | Sugar cane: mechanized harvest and power export (ETHS002) | 12.40 | *46.00* | 58.40 | 58.40 | 31.09 | *11.80* | 42.89 | 42.89 | -15.51 | |
| | Sugar cane: mechanized harvest harvesting only | -- | | -- | | 32.17 | *11.80* | 43.97 | 43.97 | | |
| | Sugar cane: power export only (ETHS003) | 20.40 | *46.00* | 66.40 | 66.40 | 40.35 | *11.80* | 52.15 | 52.15 | -14.25 | |

| | | Existing Regulation | | | | Proposed Regulation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fuel (*source of existing CI in parentheses*)** | | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Change g/MJ** | **Main Drivers of Change** |
| Sorghum Ethanol | Grain Sorghum Ethanol; 100% natural gas (ETHG001[2]) | 58.51 | *30.00* | 88.51 | 88.51 | 67.29 | *19.40* | 86.69 | 86.69 | -1.82 | • Lower Sorghum Farming Energy (-4g)<br>• Higher Fertilizer Application (11g)<br>• Larger DGS Credit (-2.8g)<br>• Higher Ethanol Production CI (1.5g)<br>• Higher Sorghum Transport due to Loss during Transport (2.9g) |
| Corn Ethanol | Corn Ethanol; 100% NG (ETHC004[3]) | 59.71 | *30.00* | 89.71 | 89.71 | 60.29 | *19.80* | 80.09 | 80.09 | -9.62 | • Lower Farming Energy (-1.2g)<br>• Higher Ethanol Production CI (1g)<br>• Higher Denaturant (0.9g)<br>• Lower Indirect Land Use (-10.2g) |

[2] For purposes of comparability, the existing corn and sorghum CIs were adjusted to reflect significant differences between existing and current energy consumption, ethanol and DGS yields, and DGS-livestock-feed displacement ratios.
[3] See footnote 2.

| | Fuel (*source of existing CI in parentheses*) | Existing Regulation | | | | Proposed Regulation | | | | Change g/MJ | Main Drivers of Change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Direct CI, g/MJ | ILUC, g/MJ | Total CI, g/MJ | EER-Adjusted CI, g/MJ | Direct CI, g/MJ | ILUC, g/MJ | Total CI, g/MJ | EER-Adjusted CI, g/MJ | | |
| Hydrogen | Hydrogen gas; central reforming of NA-NG; liquefaction and re-gasification (HYGN001) | 142.20 | | 142.20 | 56.88 | 151.01 | | 151.01 | 60.40 | +3.52 | • Higher North American NG as Feedstock Production CI (1.6g)<br>• Higher Gaseous Hydrogen Production CI (0.8g)<br>• Higher Hydrogen Liquefaction CI (0.5g)<br>• Higher Distribution and Storage CI (0.5g) |
| | Hydrogen gas; central reforming of NA-NG (HYGN002) | 133.00 | | 133.00 | 53.20 | 143.51 | | 143.51 | 57.40 | +4.20 | |
| | Hydrogen gas; central reforming of NA-NG; no liquefaction and re-gasification (HYGN003) | 98.80 | | 98.80 | 39.52 | 105.65 | | 105.65 | 42.26 | 2.74 | |
| | Hydrogen gas; on-site reforming of NA-NG; no liquefaction and re-gasification (HYGN004) | 98.30 | | 98.30 | 39.32 | 105.13 | | 105.13 | 42.05 | 2.73 | |
| | Hydrogen gas from on-site reforming of 2/3 NA-NG and 1/3 biomethane (HYGN005) | 76.10 | | 76.10 | 30.44 | 89.84 | | 87.22 | 34.89 | 4.45 | |

| | | Existing Regulation | | | | Proposed Regulation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fuel (*source of existing CI in parentheses*)** | | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Change g/MJ** | **Main Drivers of Change** |
| Electricity | Average California Electricity (ELC001) | 124.10 | | 124.10 | 36.50 | 105.16 | | 105.16 | 30.93 | -5.57 | • Lower Coal Use in Generation Mix (-5.5g)<br>• Higher Residual Oil Use (1.2g)<br>• Lower Natural Gas Use (-1.7g) |

| | | Existing Regulation | | | | Proposed Regulation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fuel (*source of existing CI in parentheses*)** | | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Direct CI, g/MJ** | **ILUC, g/MJ** | **Total CI, g/MJ** | **EER-Adjusted CI, g/MJ** | **Change g/MJ** | **Main Drivers of Change** |
| Anaerobic Digestion | Biomethane CNG derived from the high solids anaerobic digestion (HSAD) of food and green wastes (CNG005) | -15.29 | | -15.29 | -13.59 | -34.70 | | -34.70 | -30.84 | -17.25 | • Lower HSAD Process CI (-22.7g)<br>• Lower Compost Operations CI (-2.3g)<br>• Higher Credit for Compost Emissions Reduction Factor (-7g)<br>• Higher Carbon Credit Avoided (8.8g)<br>• Higher CNG Tailpipe Emissions (2.8g) |
| | Biomethane CNG from anaerobic digestion of wastewater sludge at a small-to-medium-sized wastewater treatment plant (CNG021) | 30.51 | | 30.51 | 33.90 | 30.98 | | 30.98 | 34.42 | 0.52 | The Change is Minimal due to Electricity Mix (-0.5g) |
| | Biomethane CNG from anaerobic digestion of wastewater sludge at a medium-to-large-sized wastewater treatment plant (CNG020) | 7.89 | | 7.89 | 8.77 | 7.80 | | 7.80 | 8.67 | -0.10 | The Change is Minimal due to Electricity Mix (-0.1g) |