Supplementary Material

**Supplementary Information 1 – SAF conversion pathways**

Hydroprocessed esters and fatty acids (**HEFA) process and cost data were adapted from (Humbird et al., 2011; Pearlson, 2011; Tao et al., 2014; Davis et al., 2015; Li et al., 2018; Tanzil et al., 2021). For this work, three feedstocks were utilized: fats, oils, and grease (FOGs) and two oilseed oils: edible vegetable oil and a second crop oilseed oil. The impact of feedstock is primarily from cost differences. However, losses during the cleaning process drop the fuel yield for FOGs by a small amount compared to oilseed oils. This minor loss is included in the model. The capital and operating costs for lipids cleaning are less than 10% of the respective totals. It is unlikely that a separate facility for cleaning lipids would be financially lucrative (Granjo et al., 2017). Regardless of the feedstock selected, the yield for the HEFA model is wt/wt 0.83 for total distillate after the lipids have been cleaned, which is within the range presented by De Jong et al., 2015 and Bann et al., 2017. The baseline distillate cut is listed in** Table 1**.**

The Fischer Tropsch (FT) conversion pathway includes five feedstock options. The solid waste feedstocks, agricultural residues, forest residues or municipal solid waste (MSW), are first sorted, dried and particle size reduction. The feedstock price includes this pre-processing (Brandt and Wolcott, 2021). The yield values are feedstock specific for all FT feedstocks (Swanson et al., 2010; U.S. Department of Energy, 2011; Pressley et al., 2014; De Jong et al., 2015; Niziolek et al., 2015; Brandt et al., 2020, 2021b, 2021a, 2021c). Alternatively, waste carbon can be utilized, with both flue gas and direct air capture (DAC) as source options (Isaacs et al., 2021). The financial FT TEA model that was adapted was from (Swanson et al., 2010; Niziolek et al., 2015; Albrecht et al., 2017). Each feedstock creates syngas that is upgraded to the final fuel distillates (Table 1).

**The alcohol to jet (ATJ) model starts with ethanol and was adapted from (Geleynse et al., 2018; Brandt et al., 2020). The value selected for ethanol is 0.6 wt/wt yield, which is between the values reported by (Tao et al., 2014; De Jong et al., 2015). Operating parameters can be used to change the product slate, which will be done to maximize profits. For the ATJ process scenarios, the analysis assumed that 70% of the resulting fuel is SAF and the remaining fuel is gasoline (**Table 1**).**

Supplementary Material Table : Baseline product slate for studied pathways in mass percent.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Process** | **SAF (%)** | **Diesel (%)** | **Naphtha (%)** | **Gasoline (%)** | **Propane (%)** |
| **ATJ** | **70** | **NA** | **NA** | **30** | **NA** |
| **HEFA** | **55** | **26** | **8** | **NA** | **11** |
| **FT** | **40** | **40** | **20** | **NA** | **NA** |

**Supplementary Information 2 – Detailed Incentive Information**

**In this analysis, the incentive values presented are results from generalized scenarios using existing and proposed incentive policies. Producers will need to determine the values for specific scenarios.**

**SI 2.1 CI Scores**

The carbon intensity (CI) score for each conversion pathway was determined for use in establishing the applicability and value of multiple incentives (Table 2). These values are specific to processes and feedstocks and will vary with individual locations. The authors acknowledge that other values are possible, and that the resulting incentives will be impacted.

Supplementary Material Table : CI score values for selected conversion pathways.

|  |  |  |  |
| --- | --- | --- | --- |
| Process | Feedstock | CI Score (gCO2e/MJ) | Source |
| HEFA | FOGs | 20.4 | (Port of Seattle and Washington State University, 2020; ICAO, 2021) |
| Vegetable oil | 64.9 | (ICAO, 2021) for soybean oil |
| Second crop oilseed | 13.0 | (ICAO, 2021) for brassica carinata |
| FT | MSW | 27.1 | (ICAO, 2021) with 15% non-biogenic, LEC and REC following (U.S. Environmental Protection Agency, 2018; ICAO, 2019) |
| Agricultural residues | 7.7 | (ICAO, 2021) |
| Forest residuals | 8.3 | (ICAO, 2021) |
| Flue gas\* | 9.0 | Adapted from (Isaacs et al., 2021) |
| DAC\* | 9.0 | Adapted from (Isaacs et al., 2021) |
| ATJ | Corn ethanol | 69.0 | Median, non-archived certified CI in CA LCFS program for corn ethanol |
| 2G ethanol | 27.5 | Median, non-archived certified CI in CA LCFS program for 2G ethanol |

\*Assumes green hydrogen and renewable electricity

**SI 2.2 RINs**

The values of Renewable Fuel Standard (RFS) Renewable Identification Numbers (RINs) are dependent on the RIN type and timeframe selected. The median value per RIN type between 2014-2020 was selected for this analysis (Environmental Protection Agency (EPA), 2021). Each conversion pathway has an associated RIN code (Table 3). The reported RIN values are then scaled based on the energy density of the fuel. RINs were modeled as taxable income and were subject to inflation, so the value increases over the plant life. Cellulosic diesel, D7 RINs do not have reported monetary value and thus cellulosic biofuel, D3 RIN, values were used.

Supplementary Material Table 3: RIN codes, minimum greenhouse gas emissions (GHG) reduction requirements for selected conversion pathways.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| RIN Code | GHG Reduction | Fuel Type | Pathway | Feedstock |
| D3/D7 | 60% | Cellulosic biofuel/ Cellulosic diesel | FT  ATJ | MSW, forest residue, agricultural residuals  Cellulosic ethanol |
| D4 | 50% | Biomass Based Diesel | HEFA | FOGs, second crop oilseeds for SAF and diesel |
| D5 | 50% | Advanced biofuel | FT  HEFA | Flue gas, DAC  FOGs, second crop oilseeds for naphtha and propane |
| D6 | 20% | Renewable fuel | ATJ | Corn ethanol |

RIN values for all fuels produced with MSW are reduced to account for the amount of non-biogenic material in the feedstock, for this work 15%.

**SI 2.3 Blender Tax Credits**

The biodiesel mixture excise tax credit and alternative fuel excise tax credit do not have minimum requirements for greenhouse gas emissions reductions, sliding scales, or use requirements and have values of $0.26/L and $0.13/L, respectively (U.S. Department of Energy, 2021b, 2021a). These two blenders tax credits (BTCs) apply to all conversion pathways with a 15% reduction for FT-MSW for the non-biogenic portion of the feedstock.

The proposed SAF BTC requires a minimum 50% reduction in CI, which eliminates ATJ-corn ethanol and HEFA-vegetable oil as viable conversion pathways for this incentive. The value of this incentive is proposed to be $0.40/L for 50% CI reduction and increases linearly to $0.53/L for 100% or greater reduction (Schneider, 2021). The petroleum jet fuel CI used is 89 gCO2e/MJ (International Civil Aviation Organization (ICAO), 2019). The calculated value for MSW was reduced by 15% to account for the non-biogenic material in the feedstock.

All three BTC incentives were modeled as a tax reduction incentive until the tax burden was eliminated and then as a tax-free income stream unless otherwise discussed. For years without a tax burden, the entire value was applied as tax-free income. These incentives were assumed to be available for the first ten years of a facility’s life. The value did not increase over time, diminishing the impact over time as inflation increases other costs and revenue streams.

**SI 2.4 Low Carbon Fuel Standard**

To model the California Low Carbon Fuel Standard (LCFS), a monthly weighted-average credit value of $157.8/credit was used for the 2014-2020 timeframe (CARB 2021a). One credit is earned per t of CO2e saved. The per credit value was converted to dollars per L for each type of fuel based on reduction in CI from petroleum fuel, fuel energy density and fuel density values following the methodology provided in the LCFS law (CCR 2021). The method outlined in CCR 2021 for calculating the reduction in CO2 emissions was followed using the CI scores in Table 2. It should be noted that the ICAO method for this calculation does not match the LCFS method.

The value of LCFS credits has risen over the life of the program (CARB 2021b). For this work, the value was held constant with increases only from inflation, a conservative assumption. However, the baseline value used to determine the earned credits declines over time, which means that credits earned will also decline without continuous reductions to the alternative fuel CI scores (CARB 2021b). The constant value used in this work assumes that continuous improvement matches the baseline reductions.

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