# Appendix A

## Technical Appendix for Carbon Negative Biofuels Proposal Greenhouse Gas Emissions Reductions

#### Overview and assumed inputs

Biomass to fuel conversion with carbon capture and sequestration (CCS) has enormous potential to reduce greenhouse gas emissions at both the processing facility and in replacing downstream fossil fuel combustion. This appendix details the methods and assumptions used in calculating annual and cumulative greenhouse gas emissions for this proposal, as well as cost effectiveness. In particular, the following project elements and assumptions were used as inputs to this analysis.

1. Number of projects and project size

With a total of $325 million of CPRG funding used as seed capital to galvanize private sector investment (see budget table, line item for Total Contractual – Other - Biofuels Program). The average costs to develop facilities depends on their size, with smaller, community-based facilities averaging $150 million, and larger-scale facilities averaging $500 million. This proposal is expected to provide seed funding for between six and twelve projects to be developed between 2025 and 2030. As a representative case, this analysis assumes eight community-based projects to maximize job and air quality benefits to communities, and four large-scale projects by 2030. (That said, there is uncertainty in what would be awarded and built through this proposal.) Table A1 below shows the assumed timing of when each facility would come online, which again carries some uncertainty.

**Table A1: Assumed projects and timeline**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Project Type** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| New community scale projects online | 0 | 3 | 3 | 2 | 0 | 0 |
| New large scale projects online | 0 | 0 | 1 | 2 | 1 | 0 |
| Cumulative community scale projects online | 0 | 3 | 6 | 8 | 8 | 8 |
| Cumulative large scale projects online | 0 | 0 | 1 | 3 | 4 | 4 |

1. Technologies that reduce emissions

Each project will be constructed with CCS via geological sequestration or biological charcoal (biochar). In addition to CCS at each facility, there are significant emissions reductions through the final use of hydrogen (H2) as a drop-in fuel to replace natural gas for high-heat industrial processes across a wide range of California manufacturing facilities, or to replace diesel fuel to power heavy duty hydrogen fuel cell vehicles, such as Class 8 long haul trucks.

1. Project level inputs.

Reductions in GHGs were calculated based on information provided by prospective project developers under the California Department of Conservation (DOC) Forest Biomass to Carbon-Negative Biofuels Pilot Program.[[1]](#footnote-2) This program focused on creating carbon-negative hydrogen and/or liquid fuel from forest biomass coming from forest vegetation management within California's Sierra Nevada. The Phase 1 Project Development solicited up to eight grants of $500,000 each. With input from the interagency team that evaluated these proposals, DOC selected eight Phase 1 applicants for funding in December of 2022. While information from these pilot projects is confidential, a summary of data used in the GHG analysis for this proposal is listed in Table A2 below.

**Table A2: Assumed annual project inputs for GHG reduction estimates**

|  |  |  |
| --- | --- | --- |
|  | **Community Scale** | **Large Scale Project** |
| Annual woody biomass processed  (bone dry tons) | Average: 45,000  (15,000 – 75,000 range) | Average:175,000  (100,000 – 250,000 range) |
| Annual hydrogen output  (MMBTU H2 per woody biomass bone dry ton) | 5.5 | 8 |
| Annual emissions reductions from CCS (MTCO2e) | 24,000 | 240,000 |

1. Project level fuel outputs

The cumulative amount of hydrogen produced from assumed facilities is listed in Table A3 below. These cumulative amounts rely on the estimated Fuel Yield Hydrogen Output (MMBTU H2 per Woody Biomass Bone Dry Ton) from Table A1 from a representative community scale and large scale project. Multiplying the 5.5 MMBTU per bone dry ton and 8 MMBTU per bone dry ton by the total bone try tons of biomass aggregated, and by the number of facilities that come online, results in the cumulative hydrogen production below.

**Table A3: Cumulative Hydrogen Production**

|  |  |  |
| --- | --- | --- |
|  | **MMBTU** | **Kilograms** |
| 2025-2030 | 24,932,101 | 185,508,525 |
| 2025-2050 | 176,317,161 | 1,311,896,525 |

#### Greenhouse gas emissions reductions calculations

1. Direct emissions reductions

Direct emissions reductions for community scale facilities are calculated annually by multiplying the number of community scale projects that are online in a given year by the representative emissions reductions factor for community scale projects (listed in Table A2 above). The same calculation is done for large scale projects. The two are summed for each year, resulting in total direct annual emissions reductions per year. Once all facilities are constructed (which occurs by 2029), annual emissions reductions are assumed constant to 2050 given two factors: 1) California has more expected biomass waste than could be processed by all the facilities created under this program, and 2) facilities reasonably last for 25 years with continued CCS through 2050. Cumulative direct emissions reductions are a sum of annual emissions across time periods 2025 to 2030, and 2025 to 2050 and are summarized in Table A4 below.

1. Indirect downstream emissions reductions

In addition, potential downstream, indirect emissions reductions were analyzed assuming the hydrogen from the facilities funded by this proposal is used to:

1. Displace natural gas at an industrial facility.
2. Displace diesel by providing fuel for hydrogen fuel cell trucks.

Hydrogen can be blended with natural gas to be used in buildings and industrial facilities up to 5 percent without any modifications to appliances.[[2]](#footnote-3) Burning the hydrogen produces zero GHG emissions compared to the natural gas emissions of 0.05307 MTCO2e/MMBTU.[[3]](#footnote-4)

Separately, hydrogen can be used in heavy-duty hydrogen fuel cell vehicles to displace the use of diesel trucks. To understand the GHG savings associated with the hydrogen supplied through this measure, a coefficient of expected savings per kilogram (kg) of hydrogen was created. This was done taking a few inputs, including the best available miles per kilogram (kg) efficiency of heavy-duty hydrogen trucks (roughly 15 miles / kg).[[4]](#footnote-5) Given the nascency of hydrogen fuel cell trucks, this figure is still under review and likely to improve as the market matures. For diesel trucks, the miles per gallon was assumed at nine, though this figure also varies depending on the truck, its duty cycle, load, and other factors.[[5]](#footnote-6) These inputs were used in the following equation to estimate an emissions reduction factor of fuel used in a hydrogen fuel cell truck instead of diesel. The resulting emissions reduction factor is 0. 0174 MTCO2e per kg of hydrogen produced by this proposal. For this analysis, this factor is multiplied by the production assumed in this proposal to estimate emissions reductions from this type of fuel displacement.

The total emissions reduction resulting from using hydrogen supplied through his measure in in an industrial facilities or heavy-duty transportation applications can be found in Table 4A below.

In addition, considerations were made as to how best to allocate the hydrogen fuel produced by this proposal across industrial and transportation end-uses. Ultimately, it is impossible to say with 100% certainty how hydrogen fuel would be consumed and the resulting fossil fuel displacement. However, because in industrial contexts no new equipment is required to blend hydrogen, and because California has an extensive manufacturing sector,[[6]](#footnote-7) it is safer to assume that most of the hydrogen produced under this proposal could quickly displace natural gas fuels used for industrial processes. At the same time, the diesel displaced by added hydrogen fuel supply from this proposal is not zero. For simplicity, it is assumed that two-thirds of hydrogen fuel produced would displace natural gas in industrial applications and one-third would displace diesel fuel in heavy-duty vehicles. These assumptions are incorporated into the calculation that results in the “Weighted Average” column in Table A4 below.

It is worth noting that for diesel fuel displacement, there are other uncertainties. These include the rate at which truck fleet operators adopt hydrogen fuel cell vehicles, and the extent to which those vehicles enable the retirement of diesel trucks (as opposed to being additional). In California, the new Advanced Clean Fleet Regulation (ACF)[[7]](#footnote-8) requires many fleet operators to begin using zero-emissions trucks as soon as possible (different truck types have different compliance schedules). As such, there is more certainty for fleet operators in California that zero-emissions truck adoption will displace diesel trucks. Also, while ACF is a binding regulation, it does not guarantee the funding necessary for hydrogen fuel cell technology or hydrogen fuel production and supply. Given these realities, funding sources such as CPRG directly enable GHG emissions reductions associated with increased hydrogen fuel supply.

**Table A4: Cumulative emissions reductions from direct and indirect activities**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | **Cumulative downstream emissions reductions in different applications** | | |
|  | **Cumulative direct emissions reductions from CCS** | **All H2 replaces natural gas at industrial facilities** | **All H2 replaces diesel fuel in hydrogen fuel cell trucks** | **Weighted Average**  **(2/3 natural gas, 1/3 diesel displacement)** |
| 2025 – 2030 | 3,672,000 | 1,323,147 | 3,221,587 | 1,955,960 |
| 2025 – 2050 | 26,712,000 | 9,357,152 | 22,782,722 | 13,832,342 |

Lastly, as with direct emissions from carbon capture, indirect downstream emissions reductions assume 25-year lifetimes for facilities, and annual downstream emissions reductions are constant once all facilities are built. In other words, annual emissions reductions are constant from 2029 through 2050. Cumulative indirect emissions reductions are a sum of annual emissions across time periods 2025 to 2030 and 2025 to 2050.

Figure A1 below graphs the annual and cumulative emissions reductions aggregated across both direct CCS activities and the weighted average of emissions reductions estimated across natural gas and diesel displacement in industry and heavy-duty transportation applications. Table A5 gives the annual emissions reductions from 2025 to 2030 that underpin total emissions reduced. Because annual emissions are constant from 2030 through 2050, the table omits additional years.

**Figure A1: Annual and cumulative emissions reductions**

**Table A5: Annual total greenhouse gas emissions reductions (as graphed in Figure A1 above)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **2025** | **2026** | **2027** | **2028** | **2029** | **2030*\**** |
| Total GHGs reduced directly and from Indirect, downstream fuel displacement (MTCO2e) | 0 | 130,168 | 610,012 | 1,396,143 | 1,745,819 | 1,745,819 |

*\* The annual GHGs reduced in 2029 and 2030 are constant through 2050 and not shown here.*

1. Cumulative GHG summary and cost effectiveness.

Cumulative emissions between 2025 and 2030, as well as between 2025 and 2050, are listed in Table A6 below. Dividing the total GHG cumulative emissions reductions between 2025 and 2030 by the requested $$499,602,081 in CPRG funding (per budget detail) results in a cost effectiveness of $88.77.

**Table A6: Cumulative GHG Emissions and Cost-Effectiveness Summary**

|  |  |  |
| --- | --- | --- |
|  | **Cumulative Total Emissions Reduction (MTCO2e)** | **Cost Effectiveness** |
| 2025 – 2030 | 5,627,960 | $88.77 |
| 2025 – 2050 | 40,544,342 | Not requested per NOFO guidance |

1. Department of Conservation. Forest Biomass to Carbon-Negative Biofuels Pilot Program. <https://www.conservation.ca.gov/cgs/fbp>. [↑](#footnote-ref-2)
2. CPUC. <https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-issues-independent-study-on-injecting-hydrogen-into-natural-gas-systems>. [↑](#footnote-ref-3)
3. 40 CFR Appendix Table C-1 to Subpart C of Part 98. [↑](#footnote-ref-4)
4. This coefficient was derived from CARB adopted values that underpin the relative fuel economy between fuel cell electric trucks and diesel trucks developed under the Low Carbon Fuel Standard. <https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/lcfs-regulation>. [↑](#footnote-ref-5)
5. Diesel fuel efficiency ranges, but research shows it at 8-10 mpg. For example, see North American Freight Council for Fuel Efficiency reports: <https://nacfe.org/research/run-on-less-regional/> and <https://nacfe.org/research/run-on-less-regional/>. [↑](#footnote-ref-6)
6. California Manufacturing Facts. <https://nam.org/state-manufacturing-data/2022-california-manufacturing-facts/>. [↑](#footnote-ref-7)
7. CARB. Advanced Clean Fleets. <https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets>. [↑](#footnote-ref-8)