Memo

To: Chris Malins, Cerulogy
From: Colin Murphy, NextGen Policy Center
Jeremy Martin, Union of Concerned Scientists
Date: March 9, 2018, with Author’s update March 23, 2018
Re: Basis for Carbon Capture and Sequestration Estimates

The following explains the basis for the CCS estimates available by 2030 as part of fuel pathways under the California Low Carbon Fuel Standard.

Low-CCS Estimate:

We screen for potential opportunities for high-efficiency CCS implementation under the LCFS where streams of high-concentration and/or high-pressure CO2 can be found in fuel production. After consulting with several experts, this focused on fermentation tank blow-off from ethanol production and process - but not heating- emissions from steam methane reformation (SMR) units, which produce hydrogen for refineries and chemical industries.

There are some technical challenges involved in CCS from the SMR units, related to adding a complex process in mid-stream at existing units, so as a conservative baseline assumption, these are excluded from the low-CCS estimate, leaving fermentation blow-off as the primary source of CCS credits. While any ethanol facility that ships to California could feasibly generate these credits, the Low-CCS estimate will assume only CA ethanol production facilities will do so, in part because there could be potential benefits under CA’s cap-and-trade rule or other climate policies (though no provisions yet exist) and in part to reflect conservative assumptions.

Mid-CCS Estimate:

Under the mid-CCS estimate, we assume CCS of fermentation emissions occurs at all ethanol facilities shipping to California, based on economic analysis from recent research.

In addition to ethanol facilities, this scenario assumes the technical challenges for CCS from SMR can be overcome, leading to development in this space. We limit application to SMR facilities in the Bay Area, due to proximity to a potential geological disposal site (depleted natural gas wells in the Delta) and because they are clustered in a limited geographic area, which would allow for shared pipeline and compression infrastructure.

For the mid-CCS case, we consider SMR units at Bay Area refineries, and assume all hydrogen production for these SMR units is for transportation fuel at refineries. This likely yields a slight overestimate of total transportation-related hydrogen production, which is balanced by a conservative assumption on CO2 recovery rate. CO2 would be transported by pipeline for geological storage in decommissioned natural gas wells in the Delta. Assume no additional natural gas recovery from storage wells as a result of CO2 sequestration.

For High-CCS Estimate

The High-CCS estimate assumes that post-combustion capture becomes cost-effective at prices supported by likely LCFS credit levels combined with Federal 45Q tax credit. At this level, CCS could be widely deployed at transportation fuel facilities by 2030, leading to massive LCFS credit generation. California refineries emit over 37 million tonnes of CO2 each year, of which almost 16 million tonnes comes from the Bay Area. Assuming 70% capture of just Bay Area refining yields almost 11 million tonnes of emissions reduction, well over half of predicted 2030 credit obligation for the entire LCFS program. 70% capture at all refineries, including those in Southern California, could exceed the total 2030 LCFS credit generation on its own.

In addition to refineries, cost-effective post-combustion CCS could also dramatically reduce emissions from ethanol, renewable diesel and and other transportation fuel producers, which would further increase the credit generation potential.

As a result, we will not explicitly model the High-CCS scenario and instead note that if post-combustion capture becomes widely deployed at commercial scale in CA, this would radically re-shape the LCFS credit markets and potentially crowd out investments in alternatives to petroleum fuels. If this were to happen, CARB may need to consider significant amendments to the program to ensure consistent market signals and maintain progress towards a transportation system compatible with long-term GHG-reduction goals.

In-State CCS from Ethanol Production (Present in Low and Mid-CCS scenarios):

Capture of fermentation emissions reduces ethanol CI by 32 g/MJ, per this presentation from Sean McCoy of LLNL (determined by subtracting “Fermentation CCS” CI from “Baseline” CI on slide 9 from his presentation.[1] A co-author confirmed this is an appropriate interpretation of their results). This value appears to consider life cycle emissions from the CCS system.

California produces 217.5 Million gallons of ethanol in-state at present.[2] We conservatively assume no additional ethanol production capacity to 2030.

Ethanol’s energy intensity is 81.51 MJ/gal (Physical constant, multiple sources)

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1 https://www.cslforum.org/cslf/sites/default/files/documents/tokyo2016/McCoy-BiofuelsCCS-TG-Tokyo1016.pdf.

2 http://www.neo.ne.gov/statshtml/121.htm

This yields:

217,500,000 (gal/year) * 81.51 (MJ/gal) * 32 (grams/MJ) * 1/1000000 (tonnes/gram) ≅ **567,000 tonnes/year**

Out-of-State Ethanol CCS from Ethanol Production (Present in Mid-CCS Scenario)

Depending on scenario and modeling assumptions, CA conventional ethanol consumption in 2030 varies between 1 and 1.5 billion gallons per year (LCFS Draft Compliance Scenario Calculator). A high-ethanol scenario, such as broad deployment of E15, or other high-ethanol blends could get up to 2 billion gallons of ethanol. Using the 7.5 lb/gallon figure from above, this results in a maximum possible fermentation CO2 emission rate of 6.8 million tonnes/year from fermentation emissions associated with production of ethanol for use in California.

Sanchez, Johnson, McCoy and Turner,[3] indicate that 34 million tonnes/year of CO2 from Midwest ethanol plants could be sequestered at a cost < $60/tonne. This is significantly lower than the combined value of LCFS credits and Section 45Q credits. [See footnote for update]

Since the potential for CO2 sequestration of ethanol fermentation emissions greatly exceeds the emissions associated with California's consumption at prices well below that which would be available to producers under likely 2020-2030 conditions, the Mid-CCS scenario assumes that all ethanol fermentation emissions would be sequestered.

Repeating the methodology from the In-State calculation, based on an estimated 1.2 billion gallons total ethanol produced, of which 765 are corn, in the *Steady Progress* scenario yields. We assume only corn ethanol is paired with CCS:

765,000,000 (gal/year) * 81.51 (MJ/gal) * 32 (grams/MJ) * 1/1000000 (tonnes/gram) ≅ **2 million tonnes/year (1.995 million without rounding)**

CCS on SMR units in Northern CA (Present in Mid-CCS Scenario)

Soltani, et al.,[4] indicates that the most efficient phase of the process at which to implement CCS is after the syngas shift but before pressure-swing separation, due to the high pressure of the gas stream at this point. The process can be optimized for CCS potential, at which 65% of total process CO2 emissions could be recovered (assuming 90% of CO2 capture efficiency) or

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[3] http://dc.engconfintl.org/cgi/viewcontent.cgi?article=1041&context=co2_summit3.

Author's update: A more comprehensive explanation of this work was accepted for publication after this memo was first published: D.L. Sanchez, N. Johnson, S. McCoy, P.A. Turner, K.J. Mach. "Near-term deployment of carbon capture and storage from biorefineries in the United States" Proceedings of the National Academies of Sciences (In Press).

[4] https://www.sciencedirect.com/science/article/pii/S0360319914027566

optimized for maximum hydrogen production rate, at which 36% of CO2 emissions could be recovered. (Estimated by dividing the process emissions line by total emissions line for all S/C ratios in Table 2).

H2A modeling from the DOE[5] claims 81% of total CO2 could be captured by CCS (determined by dividing the mass flow of CO2 from the CO2 stream by the sum of CO2 mass flows from the CO2 stream and flue gas stream).

In evaluating BAAQMD monitoring reports for SMR units, it appears that many are run below their rated capacity, presumably to match demand. Given the excess theoretical capacity, it is reasonable to assume that the potential value of CCS in excess of $150/ton from LCFS credits and Federal 45Q tax credits would be a sufficient incentive to run the SMR under conditions nearer to those optimal for CO2 recovery than for hydrogen production. Accordingly, we assume a net CO2 sequestration rate near the upper end of the range from the Soltani paper, but well below the theoretical limit proposed by DOE: 60%.

Relevant SMR Units and Emissions:

Using the EPA facility-level GHG emission inventory,[6] we select Subpart P emissions from Northern CA refineries and SMR facilites known to sell primarily to refineries.

Facility	**CO2 Emissions (tonnes/yr)**
Shell Martinez Refinery	816174
Valero Benicia Refinery	948212
Tesoro Golden Eagle Refinery	562646
Chevron Richmond Refinery	1334862
Air Products & Chemicals Martinez (Shell)	723983
Air Products & Chemicals Martinez (Tesoro)	264024
Air Liquide Rodeo (Shell)	769835
Shell Rodeo	111304
SUM	5,531,040

[5] DOE H2A Project "Current Central Hydrogen Production from Natural Gas with CCS" https://www.hydrogen.energy.gov/h2a_prod_studies.html

[6] https://ghgdata.epa.gov/ghgp/main.do

Based on the 60% sequestration assumption, this yields **3.3 million metric tonnes** per year of sequestration.

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