October 9, 2020

Richard Corey
Executive Officer

Rajinder Sahota
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Air Resources Board
1001 I Street
Sacramento, CA 95812

(Letter submitted electronically as Comment to LCFS Public Workshop)

Request to Integrate Bio-oil Sequestration into Low Carbon Fuel Standard

Dear Richard, Rajinder, and Arpit,

This letter is submitted on behalf of Charm Industrial, Inc. ("Charm Industrial" or "Charm"). Charm Industrial is an early-stage hardware startup in San Francisco working to return the atmosphere to pre-Industrial Revolution CO_2 levels of 280 ppm. The company is composed of mechanical, electrical, and fabrication engineers who are focused on identifying the most innovative and impactful carbon reduction technologies. Charm Industrial is the world's leading developer of bio-oil sequestration, having secured funding for two demonstration projects. Like direct air capture and carbon sequestration, bio-oil sequestration has tremendous potential to affirmatively reduce the presence of greenhouse gases ("GHG") in the atmosphere. Charm Industrial is therefore requesting that the California Air Resources Board ("CARB") integrate bio-oil sequestration into the Low Carbon Fuel Standard ("LCFS") as further described by this comment letter.

Bio-oil Sequestration

Charm Industrial is developing two related bio-oil sequestration strategies. The first strategy is to: 1) produce bio-oil through fast pyrolysis of waste biomass, 2) transport the bio-oil to an injection well, 3) prepare the bio-oil for injection, and 4) inject the bio-oil into geological formations. The first step of the second strategy also entails producing bio-oil through fast pyrolysis of waste biomass. In the second strategy, once the bio-oil is produced, it is split into two streams with the first portion of the bio-oil utilized as a low carbon intensity ("CI") feedstock to produce hydrogen. The second portion of the bio-oil is directly sequestered in the same manner as in the first strategy.

The injection wells for the bio-oil are EPA Class I industrial disposal wells or Class V salt caverns. The process effectively takes atmospheric CO_2, captures it in biomass, converts the biomass to a liquid similar to crude oil, and injects the bio-oil into rock formations that have stored crude oil for hundreds of millions of years. This process performs well from a permanence standpoint in that while supercritical CO_2 injected into geological formations is buoyant and pushes towards the surface thereby creating monitoring concerns; bio-oil is denser than brine, sinks within the containing formation, and auto-polymerizes into a semi-solid material, making it naturally suited to permanent sequestration.

California Policy Requires Decarbonization of the Transportation Sector

Pursuant to SB 32 and AB 197, California must reduce its GHG emissions 40% below 1990 levels by 2030 necessitating dramatic GHG reductions compared to current policies. Transportation emissions are the dominant GHG emissions source, constituting 41% of California's total GHG emissions of 424.1 $MMTCO_2e$.[1] Transportation GHG emissions have clearly emerged as the most difficult sector to decarbonize with transportation's rising from 35% of California's GHG emissions in 2015 to 41% in 2017.[2]

Pursuant to Governor Brown's Executive Order B-55-18, California has a statewide goal to achieve carbon neutrality as soon as possible, and no later than 2045, and to achieve and maintain net negative emissions thereafter in addition to statewide targets of reducing GHG emissions including SB 32 and AB 197.[3] In addition, the Executive Order provides that, "The California Air Resources Board shall work with relevant state agencies to ensure future Scoping Plans identify and recommend measures to achieve the carbon neutrality goal."

Bio-oil Sequestration Provides Substantial Decarbonization Potential

To identify negative emissions pathways that physically remove CO_2 from the atmosphere and that can enable California to meet its goal of achieving carbon neutrality by 2045, the Lawrence Livermore National Laboratory developed a recently published report entitled, Getting to Neutral, Options for Negative Carbon Emissions in California (the "Getting to Neutral Report").[4] The Getting to Neutral Report identifies the conversion of waste biomass to bio-oil to advanced biofuels as the most important of the three primary pillars for California to reach 125 million tons of negative emissions annually. As discussed above, the second of Charm Industrial's sequestration strategies is the conversion of bio-oil to hydrogen coupled with partial bio-oil

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[1] Air Resources Board, Public Workshop on the Transportation Sector to Inform Development of the 2030 Target Scoping Plan Update, September 14, 2016, https://www.arb.ca.gov/cc/scopingplan/meetings/091316/FINAL%20Scoping%20Plan%20Transport%20Workshop.pdf (last viewed September 19, 2016), at slide 11 and 14.

[2] Presentation of Executive Officer Richard Corey, slide entitled "Transportation Remains a Key Focus," presented at Argus Biofuels & Carbon Markets Summit, October 22, 2019, at slide 11.

[3] Executive Order B-55-18, available at https://www.ca.gov/archive/gov39/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf

[4] Sarah E. Baker, Joshuah K. Stolaroff, George Peridas, Simon H. Pang, Hannah M. Goldstein, Felicia R. Lucci, Wenqin Li, Eric W. Slessarev, Jennifer Pett-Ridge, Frederick J. Ryerson, Jeff L. Wagoner, Whitney Kirkendall, Roger D. Aines, Daniel L. Sanchez, Bodie Cabiyo, Joffre Baker, Sean McCoy, Sam Uden, Ron Runnebaum, Jennifer Wilcox, Peter C. Psarras, Hélène Pilorgé, Noah McQueen, Daniel Maynard, Colin McCormick, Getting to Neutral: Options for Negative Carbon Emissions in California, January, 2020, Lawrence Livermore National Laboratory, LLNL-TR-796100, available at https://www-gs.llnl.gov/content/assets/docs/energy/Getting_to_Neutral.pdf (footnotes omitted).

sequestration. This strategy is comparable to the Getting to Neutral Report's primary pillar of carbon neutrality but differs in that rather than converting all of the bio-oil to carbon neutral or carbon negative transportation fuels, Charm's second strategy avoids the capital expenditures associated with developing a biorefinery with the capacity to process all of the bio-oil and also eliminates the need to capture and sequester the gaseous CO_2. The first bio-oil sequestration strategy identified by Charm Industrial completely eliminates the biorefinery component by proceeding directly to sequestration.

While distinguishable from the Getting to Neutral Report's primary pillar in these respects, Charm's bio-oil sequestration strategies focus on precisely the same core objective: permanently removing atmospheric CO_2 and sequestering the carbon content in geological storage. Effectively, these approaches seek to turn back the clock on the massive relocation of carbon from the earth into the atmosphere that has occurred through centuries of fossil fuel extraction and combustion.

The Getting to Neutral Report estimates the total quantity of waste biomass available in California annually to be 56M bone dry tons.[5] As used in the report, the phrase "Waste Biomass" refers to trash, agricultural waste, sewage and manure, logging, and fire prevention activities. Charm Industrial has identified wood waste and agricultural waste as acceptable feedstocks for either of their bio-oil strategies. According to the Getting to Neutral Report, these Waste Biomass feedstocks are anticipated to be readily available in California from the present until 2045, with the availability estimated at 34.4M BDT/year in 2025, rising to 36.7M BDT/year in 2045.[6] Thus from a feedstock perspective, the strategies proposed by Charm Industrial are demonstrably scalable and the feedstock is locally available.

Bio-oil Sequestration has Garnered Attention from Decarbonization Experts

While nascent, Charm Industrial's strategies relating to bio-oil sequestration have already garnered attention from decarbonization experts and development funding from companies relying on these experts to advance the most promising long-term technologies. Stripe is a technology company that builds economic infrastructure for the internet.[7] Stripe invests a minimum of $1M annually in the most promising solutions to fight climate change.[8] To guide its investment decisions, Stripe has convened a panel of expert reviewers that includes: Dr. Jennifer Wilcox (Professor, Worcester Polytechnic Institute), Dr. Phil Renforth (Associate Professor, Heriot-Watt University), Dr. Steven Hamburg (Chief Scientist, Environmental Defense Fund), Dr. Jane Zelikova (Chief Scientist, Carbon180), Andrew Bergman (PhD candidate, Harvard), Dr. Bill Anderegg (Assistant Professor, University of Utah), Dr. Colin McCormick, and Dr. Zara L'Heureux.9 Stripe was Charm Industrial's first customer and established an agreement with Charm to purchase 416 tons of carbon storage at $600 per ton.

[5] Id, at p. 4.
[6] Id. at p. 45, Table 20.
[7] Stripe Website, "About Stripe," at https://stripe.com/about .
[8] Id., "Shopify's Sustainability Fund," at https://www.shopify.com/about/environment/sustainability-fund?itcat=sustainability-fund&itterm=inter-bottom-nav-biomass
[9] Id., "Stripe's first negative emissions purchases," at https://stripe.com/blog/first-negative-emissions-purchases#recognition-footer

Similarly, Shopify invests a minimum of $5M annually in the most promising solutions to fight climate change.[10] Shopify has identified ten industries that have the potential to reverse climate change including carbon removal.[11] Charm was selected to receive funding from Shopify in its Frontier Portfolio for Biomass. Charm's co-founder, Shaun Meehan, was quoted on the Shopify website and described Charm's process as follows: "Over the past century, humans have extracted and burned hundreds of gigatons of fossil fuels, increasing atmospheric CO_2 from 280 to 415 ppm. Charm has developed a new, patent-pending method to help reverse that: bio-oil sequestration."[12]

<u>Recommended LCFS Regulatory Structure</u>

CARB's development of the CCS Protocol for the LCFS in last major rulemaking paved the way for CARB to similarly credit and incentivize bio-oil sequestration. Pursuant to 17 CCR §95490(a), the following types of carbon capture and sequestration (CCS) projects and pathways are authorized to generate LCFS credits:

(a) *Eligibility.* The following entities are eligible to submit project applications and, if approved, receive CCS credits, in accordance with following protocol which is incorporated herein by reference and is referred to as the "CCS Protocol" hereafter.

Industrial Strategies Division, California Air Resources Board. August 13, 2018. Carbon Capture and Sequestration Protocol under the Low Carbon Fuel Standard.

1) Alternative fuel producers, refineries, and oil and gas producers that capture CO_2 on-site and geologically sequester CO_2 either on-site or off-site.
2) An entity that employs direct air capture to remove CO_2 from the atmosphere and geologically sequester the CO_2. If CO_2 derived from direct air capture is converted to fuels, it is not eligible for project-based CCS credits. However, applicants may apply for fuel pathway certification using the Tier 2 pathway application process as described in section 95488.7.

Importantly, pursuant to §95490(b)(1), "Projects and fuel pathways claiming CCS credits must comply with the CCS Protocol. To be considered in compliance with the CCS protocol, a project must be issued executive orders and meet all the requirements throughout the project life in accordance with the permanence requirements of the CCS protocol."

While Charm's first strategy of direct bio-oil sequestration is distinct from direct air capture in some respects, the processes are similar in terms of removing atmospheric CO_2 and sequestering

[10] Shopify Website, "Shopify's Sustainability Fund," at https://www.shopify.com/about/environment/sustainability-fund?itcat=sustainability-fund&itterm=inter-bottom-nav-biomass
[11] Id., "Shopify Blog," at https://www.shopify.com/blog/sustainability-fund
[12] Id., "Frontier Portfolio Biomass," at https://www.shopify.com/about/environment/sustainability-fund/biomass?itcat=sustainability-fund&itterm=inter-main-page-cards-index

it underground on a permanent basis. The Charm Industrial process effectively utilizes the carbon capturing capabilities of biomass to capture the CO_2 then concentrates the CO_2 into liquified form through the bio-oil production process. Therefore, it appears that a regulatory approach that is consistent with §95490(a)(1) could also apply for bio-oil sequestration. Regarding Charm's second strategy of bio-oil sequestration as a component of hydrogen production, this appears to be consistent with either the provision for direct air capture that is utilized to convert CO_2 to fuels pursuant to §95490(a)(2) and also to the production of alternative fuels with sequestration pursuant to §95490(a)(1). Thus for the LCFS crediting component, bio-oils could be integrated into the LCFS regulatory framework with language clarifying the activities qualifying for credit generation.

The most substantive addition to the LCFS regulations would be to either expand the existing CCS Protocol to encompass bio-oil sequestration, or the development of a comparable protocol that is focused solely on bio-oil sequestration. The attached report from SCS Engineers contains an assessment of the stability and long-term containment integrity of solutioned salt caverns and determines that solutioned salt caverns provide a suitable geological sequestration site for bio-oils. The SCS Engineers report concludes, "The factors outlined above support the conclusion that bio-oil can be effectively sequestered in engineered salt caverns and maintaining geological confinement and permanence of sequestration for at least 100 years but likely as long as 1,000 years."

Charm Industrial looks forward to working with CARB to further establish the benefits of recognizing bio-oil sequestration within the LCFS, and to provide input into the establishment of an effective regulatory framework to implement this objective.

Conclusion

Thank you for your consideration of our input to this LCFS rulemaking informal workshop. We look forward to the opportunity to discuss this policy concept at the LCFS Policy Workshop on October 15th.

Sincerely,

Graham Noyes

Cc: Peter Reinhardt, Charm Industrial Inc.

May 27, 2020
File No. 27220169.00

Transmitted electronically to: shaun@charmindustrial.com

Mr. Shaun Meehan
Founding Engineer
Charm Industrial Inc.
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Subject: Geologic Sequestration of Bio-oil in Solutioned Salt Caverns

Dear Mr. Mehaan:

SCS Engineers has prepared an assessment on the stability and long-term containment integrity of solutioned salt caverns that confirms it is a suitable geologic sequestration alternative for bio-oils. This assessment is based on the authors 30 years of experience as a geologist, with specialized expertise in the disposal and geologic isolation of hydrocarbons, natural gas, brines and industrial wastewaters in porosity storage and mined solution caverns across the United States, with an emphasis on the geologic integrity of engineered salt caverns in the mid-continent region. A wide base of research conducted by academia, National Laboratories (Battelle, Sandia, Los Alamos etc.) and industry that are referenced herein supports the assessment. The technical merits of this sequestration option are also supported by a robust and mature regulatory program administrated by the Kansas Department of Health and Environment (KDHE) which has been designated by the United States Environmental Protection Agency (EPA) has having primacy to regulate the proposed activities in accordance with applicable state and federal statutes.

The purpose of this evaluation is to summarize that sequestration of bio-oil in an engineered, solutioned salt cavern meets or exceeds the current carbon capture and storage (CCS) modeling and geologic containment provisions commonly used for liquid CO_2. It should also be noted that this specific bio-oil cavern sequestration application is not a valid technical comparison to current CCS sequestration projects or commonly referenced containment evaluations. We used a 100 year standard as the criteria for permanence since it is the criteria the California Air Resources Board (CARB) has established for this project.

Introduction:

There is a wide base of CCS research in the body of literature related to the geologic sequestration of CO_2. However, it is important to note that this research is primarily focused on sequestering compressed, industrial grade, CO_2 in porosity rock matrices across highly variable geologic environments (IOCC, 2005). This form of CO_2 behaves as a multi-phase liquid in the subsurface unless kept super-critical under high pressures (and usually depths over 4,000 feet). All the CCS standards for demonstrating geologic integrity over time account for the highly variable nature of subsurface conditions, and multi-phase subsurface transport of large scale volumes (tens to hundreds of millions of metric tons per year) of CO_2 (Battelle, 2011). They consider timeframes from 100 to 1,000 years (IPCC, 2005) that considers all artificial penetrations (wells, borings, mines etc.) and faults the CO_2 might encounter as it moves underground over areal extents that can exceed 500,000 km^2 (Battelle, 2011). These factors are evaluated because pure CO_2 tends to rise in these environments and could ultimately return to the atmospheric carbon cycle if not effectively contained.

CO_2 as considered in the current body of CCS research is injected as a super critical liquid or gas and has a wide range of densities and viscosities that make it easy to move in the subsurface and requires a large, validated data set to model accurately. This is why typical CO_2 sequestration efforts require such robust measures to document long-term containment and integrity of the geologic system including the multiple variables that must be considered to confirm the CO_2 stays isolated from drinking water and the atmosphere. These variables include:

- Geologic suitability of caprock, reservoirs, native fluids and their variability with depth and distance from the injection sources on a local and regional scale
- Local and regional groundwater and deep saline aquifer flow regimes
- Quality of available information on the geologic systems
- Artificial penetrations (test borings, wells of all types, mines etc.) that are or may be present in the large study area.

<u>Permanence of Bio–oil Sequestration in Solutioned Salt Caverns:</u>

The geologic sequestration of CO_2 as a supercritical liquid or vapor phase as outlined above requires the extensive evaluations and considerations to document long term containment. Sequestration of a single phase, dense bio-oil form of CO2 within an engineered, solutioned salt cavern mitigates the need for such extensive evaluations for the following reasons:

- The bio-oil is a single phase liquid at the depths and pressures encountered in the salt caverns. It is more dense than the surrounding brines (Schmidt, et, al., 2019) and will sink once emplaced in the caverns, limiting its geologic mobility in the subsurface.
- Bio-oil stability over time was evaluated by aging studies (Wefpei, et, al., 2019) and did not indicate formation of a gas fraction during degradation process. This study did note the increased viscosity over time and supports the use of the material for cavern stabilization as part of the sequestration process.

- The salt caverns are engineered subsurface features that have minimum design and operational criteria that are well defined by over 60 years of industrial use and robust regulatory oversight programs (Ratigan, 2002).
- The potential corrosive effects of the bio-oil on the well casing and injection tubing are addressed by operational factors that include:
  - Dilution with a soil matrix and saturated brines during emplacement
  - Co-mingling of the bio-oil with other solids that reduce the overall percentage of bio-oil in the cavern to a relatively small portion of the material contained
  - Flushing the portions of casing and tubing with brine after the emplacement procedure.
  - Limiting the filling of the cavern to prevent bio-oil contact with the casing once cavern capacity as measured by sonars indicates fill material is near the casing shoe.
- The salt units surrounding the caverns have no measurable porosity or permeability and provide a much more effective geologic seal than typical CCS projects in saline aquifers or depleted oil and gas reservoirs (Dusseault et, al. 2010).
- The regulatory requirements of monitoring the cavern size before, during and prior to closure with sonar provide a demonstration that long term conditions are known prior to the final plugging.
- The salt caverns have a single point of entry and the demonstration of mechanical integrity via pressure testing and logging further demonstrate containment (Dusseault, 2010 & Ehgatner, 1994).
- The engineered characteristics of the caverns casing string and ability to accurately document cavern size, geometry and stability prior to closure eliminates the need for evaluating large areas for review for artificial penetrations or faults.
- Salt cavern owners/operators are required to demonstrate financial assurance sufficient to allow the regulatory agency to conduct proper closure and long term facility monitoring in the event of operator default or non-compliance with permit provisions (K.A.R 45).
- Minimal injection pressures are used to sequester the bio-oil and the regulatory program that has jurisdiction limits injection pressures to 0.75 psi/ft. which is well below the salt fracture pressure thus maintaining the geologic seal provided by the salt formation (KDHE, 2011).
- The Hutchinson Salt is the geologic unit the salt caverns were engineered and dissolutioned within. The salt has an upper and lower confining unit of dense, low permeability shale that provides additional layers of geologic integrity for demonstrating sequestration
- Modelling of long term salt behavior of caverns used in the US strategic petroleum reserve conducted by Sandia National Laboratories concluded there is over a 99% certainly that caverns maintain their geologic integrity for up to 1,000 years (Ehgartner, 1994)

The factors outlined above support the conclusion that bio-oil can be effectively sequestered in engineered salt caverns and maintaining geological confinement and permanence of sequestration for at least 100 years but likely as long as 1,000 years.

References are cited below and attached since a portion of the literature is by subscription only.

Sincerely,

Monte R. Markley

Monte R. Markley, P.G.
Vice President/Senior Project Director
SCS Engineers

MRM/SH

cc: Dual Bringer – SCS Engineers

Attachments: References as noted below

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