July 9, 2020

Andrew White, CEO
CHAR Technologies
andrew.white@chartechnologies.com

RE: PRELIMINARY CARBON INTENSITY IMPACT ANALYSIS FOR APPLYING THE PYROLYSIS TECHNOLOGY ON DIGESTATE FROM ANAEROBIC DIGESTION

Dear Mr. White,

This letter report was prepared for CHAR Technologies (referred to as CHAR hereafter) to provide a preliminary carbon intensity (CI) impact analysis for High Temperature Pyrolysis (HTP)technology when it is used to treat digestate from anaerobic digestion (AD). The CI was assessed using the standards and approach of life-cycle analysis (LCA) adopted under the Low Carbon Fuel Standard (LCFS) program in California. This letter report represents the opinion of EcoEngineers staff specializing in providing services for the LCFS program since 2013. The following sections provide background, procedures, analysis results, recommendations, and conclusions.

1.0 Purpose of Analysis

This letter report is provided at the request of CHAR to evaluate the CI impact of HTP technology when it is used to treat digestate from anaerobic digestion. Specifically, this report focuses on the analysis of a hypothetical (generic) dairy manure AD project, because this type of project is the most financially attractive in today's market with the support of California LCFS and Federal RFS programs.

2.0 Background of CHAR and Pyrolysis

CHAR Technologies Ltd is a leading cleantech development and environmental services company listed on the TSXV ('YES.V'). CHAR specializes in delivering innovative service and technology solutions that are environmentally sustainable and cost-effective for clients. CHAR challenges the boundaries of technology, exemplified by the development and use of advanced high temperature pyrolysis technology to convert low-value solid waste streams into three valuable outputs – heat, energy and biocarbons. [1]

HTP technology is a thermal process, which results in the thermal decomposition of organic material at elevated temperatures in the absence of oxygen. The HTP process converts organic material to syngas, heat and solid biocarbon products. The syngas and heat can be used to offset non-renewable on-site energy requirements, while the biocarbon can be used as an energy source, to treat hydrogen sulfide and odour, and as a high-value soil amendment product with additional carbon sequestration benefits.

The hypothetical project includes diverting manure to an anaerobic digester, producing biogas, cleaning and purifying the biogas, and then injecting it into an interstate natural gas pipeline. The ultimate use of the purified biogas is expected to be transportation fuel in the form of compressed natural gas (CNG) in California. The by-product solid anaerobic digestate is then converted by CHAR's HTP technology into additional renewable and valuable outputs.

[1] https://www.chartechnologies.com/

3.0 Procedures and Methodology Used to Evaluate CI and the CI Reduction Strategies

EcoEngineers staff performed the following work to estimate the CI of the transportation fuel produced in the proposed project:

- Gathered information on the proposed project from CHAR staff and conducted calls to gain a general understanding of the project
- Reviewed data provided by CHAR and resolved questions on the data for clarity
- Processed the data to create model inputs for the CA-GREET 3.0 models. The CA-GREET 3.0 tool used specifically for this project is Tier 1 Simplified CI Calculator for Biomethane from Anaerobic Digestion of Dairy and Swine Manure [2]
- Summarized the outputs from the CA-GREET 3.0 models, the impacts of different components, and any additional considerations that CHAR staff should be aware of

4.0 Data, Assumptions, and Scenarios for the Project

CHAR provided the following document for the project:

- *Copy of CHAR LCA Analysis Data Request 2020.04.08*
- *CHAR Technologies Ltd - Value of Biogas West 2020 Presentation*
- *Additional information provided via phone call and email communication*

Table 1 summarizes the key parameters of the process based on documents received from and the communication with CHAR Staff, as well as assumptions based on industrial experience related to AD projects. Other information can be found in above documents.

Table 1. Key Parameters

Parameter	Value	Unit
# of cows	12,000 milking cows	
Digester type	Enclosed Vessel	
Raw biogas production	37,888,667	SCF/Month
Biogas methane content	60	%
Natural gas use	2,250	MMBtu/month
Grid electricity use*	219,000	kWh/month
Biomethane injected into pipeline	22,501	MMBtu/month
Pipeline transport distance to California	2,000	Miles
Digestate production	46,000	MT/year
Digestate moisture	65	%
Biocarbon production	3,780	MT/year
Syngas available	2,522	MJ/hour
Stable C in biocarbon for C sequestration	80	%

*For pyrolysis process only

[2] https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation

To illustrate the CI impact of different parameters, four scenarios were analyzed in this study:

Scenario I: Baseline in which digestate is stored in effluent ponds (storage lagoons)

Scenario II: Only consider the CI benefit from eliminating the residual VS going into effluent pond

Scenario III: In addition to Scenario II, consider the CI benefit from displacing Natural Gas with syngas

Scenario IV: In addition to Scenario III, consider the CI benefit from biocarbon land application and the subsequent carbon sequestration

5.0 Results and Discussion

Table 3 shows the CI results from the four scenarios analyzed in this report.

Table 3. CI Analysis Results (Numbers are rounded.)

Scenarios	CI (g CO_2e/MJ)	Improvement compared to previous scenario
I	-217	
II	-236	19
III	-242	6
IV	-251	10
Total (IV vs. I)		35

Several key findings from the results include:

1. The avoided methane emission credits are the single biggest factor that influences the final CI of the transportation fuel. By building the AD and diverting the manure from a pond (lagoon) system, the project produces useful transportation fuel and avoids the uncontrolled biomethane emissions from an open pond system. Therefore, the avoided methane emissions are credited back to the biogas produced by the project, resulting in a low negative CI transportation fuel. This is not directly related to the pyrolysis of digestate, but demonstrates why this type of project is attractive in current transportation fuel market.

2. In the CA-GREET 3.0 model, the default assumption for digestate treatment is that 100% of the VS in digestate goes into a digestate pond (lagoon), and continues to emit methane from there. By simply removing this VS from the anaerobic condition, the CI can be 19 points better. When syngas is used as process energy to displace a fraction of the natural gas, the CI further decreases by 6 points. When the carbon sequestration credits are considered when biocarbon is land applied, an additional 10 points can be reduced. The total CI reduction in this case is 35 g CO_2e/MJ.

3. This analysis only shows the magnitude of the CI impact. When this technology is used in a specific project, project-specific data needs to be used to calculate the project-specific CI impact.

4. This project is assumed to be located in Wisconsin. Generally speaking, if all the project parameters remain the same, when the project is located in a warmer place, the CI benefit from using the pyrolysis could be more significant.

5. Under current LCFS regulations, the CI reduction from eliminating the VS going into storage lagoons and from displacing natural gas with syngas is relatively straightforward and easy to quantify. The CI reduction from biocarbon carbon sequestration is less straight forward, because of the uncertainty around the fate of the carbon in biocarbon. Whether this credit can be claimed is subject to the discretion of CARB. Further regulatory engagement may be needed.

6.0 Conclusions

Having reviewed the information provided by CHAR, and combining it with the assumptions of a hypothetical dairy manure biogas project, EcoEngineers evaluated the CI impact of the pyrolysis technology when it is used to treat the digestate by-product from the project. The CI impact in this study ranges from 19 to 35 g CO_2e/MJ, depending on what credits can be claimed. At an LCFS credit price of \$200/MT CO_2, this represents an additional LCFS credit revenue of \$4 to \$7.4 per MMBtu RNG.

This report is based on the information provided by CHAR, current regulations, previous experience working with CARB staff, and the expert opinion of EcoEngineers staff. This report is intended solely for CHAR and is not intended for use by any other parties except with the express permission of CHAR.

Sincerely,

Dr. Zhichao Wang, Ph.D, P.E.
Senior Engineer / Carbon Analyst

Background & Qualifications of EcoEngineers

EcoEngineers is a leading renewable energy consulting firm and USEPA approved auditor with core services that include audit, compliance management, and consulting services. Our consulting team is comprised of engineers, regulatory and compliance specialists, financial and life-cycle analysts - all of whom hold deep expertise in federal, state, and international energy regulations that set a price on carbon and create carbon markets. The low carbon value of renewable energy is represented by the economic value of fungible energy credits. EcoEngineers work improves regulatory compliance and quality of credits to protect the value of investments.

EcoEngineers provides LCFS services to renewable diesel, biodiesel, cellulosic ethanol, renewable natural gas and other renewable fuel producers and has extensive experience working with the California LCFS program and the CA-GREET models. EcoEngineers has several full-time engineers dedicated to modeling fuel pathways using a variety of LCA tools and has submitted over 150 applications to California Air Resources Board (CARB) for registration under the LCFS. EcoEngineers has successfully helped producers to obtain more than 50 certified pathways under the newly adopted LCFS regulation effective since January 2019.

EcoEngineers provides RFS2 New Pathway Applications, Efficient Producer Petitions, 3rd Party Engineering Reviews, Part 80 Registrations and other services to producers of renewable diesel, ethanol, biodiesel, heating oil, renewable natural gas and other RFS participants. Additionally, as part of the suite of compliance services we offer, EcoEngineers is an EPA approved Q-RIN Quality Assurance Program (QAP) provider under the RFS program and conducts quarterly audits of over 160 domestic and international renewable fuel production facilities to ensure compliance under federal regulations. Our compliance management services provide RIN Academy Workshops, guidance on RIN generation protocol and compliance monitoring plans, and a proprietary RIN management platform that managed over 3 Billion RINs transactions in 2018.