Novel Algae Technology to Utilize CO_2 for Value Added Products

Field Test Final Report

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Introduction:

As part of Helios-NRG, LLC (Helios) novel algae process development for carbon capture and utilization, Helios has completed a three-month (June – September 2022) field test at the National Carbon Capture Center (NCCC) as part of U.S. Department of Energy project DE-FE-0031710 "Novel Algae Technology to Utilize CO_2 for Value Added Products". Over the past decade, Helios has been developing a suite of integrated technologies to capture CO_2 from coal plant flue gas using a novel algae culture system and subsequent processing steps to utilize the algae for revenue-generating products to offset the cost of capture. The Multi-stage Continuous (MSC) algae technology is being developed to operate on a post-flue gas desulfurization (FGD) stream from coal power plant in the outdoors (sunlight). Extensive testing of the MSC leading up to the field test were conducted using simulated flue gas. Upon completion of the NCCC field test, a major step forward in the technology development was demonstrated with successful MSC operation in the coal power plant environment. The test results met the targets of simultaneous high biomass productivity coupled with high CO_2 capture efficiency, and was the first biological/algae-based system to be tested at NCCC.

The complete suite of technologies envisioned at the commercial scale is shown in Figure 1. The MSC utilizes CO_2-rich flue gas, sunlight and wastewater nutrients to produce algal biomass. The two streams exiting the MSC continuously are (1) a CO_2 depleted gas stream, and (2) the culture liquid harvest. The algae liquid is dewatered and the algae processed for products in biofuels, feed, and nutraceuticals. The products can be sold directly to existing markets. Water is conserved in the process by recycling what is collected from dewatering back to the algae culture. At NCCC, only the MSC portion of the technology was tested.

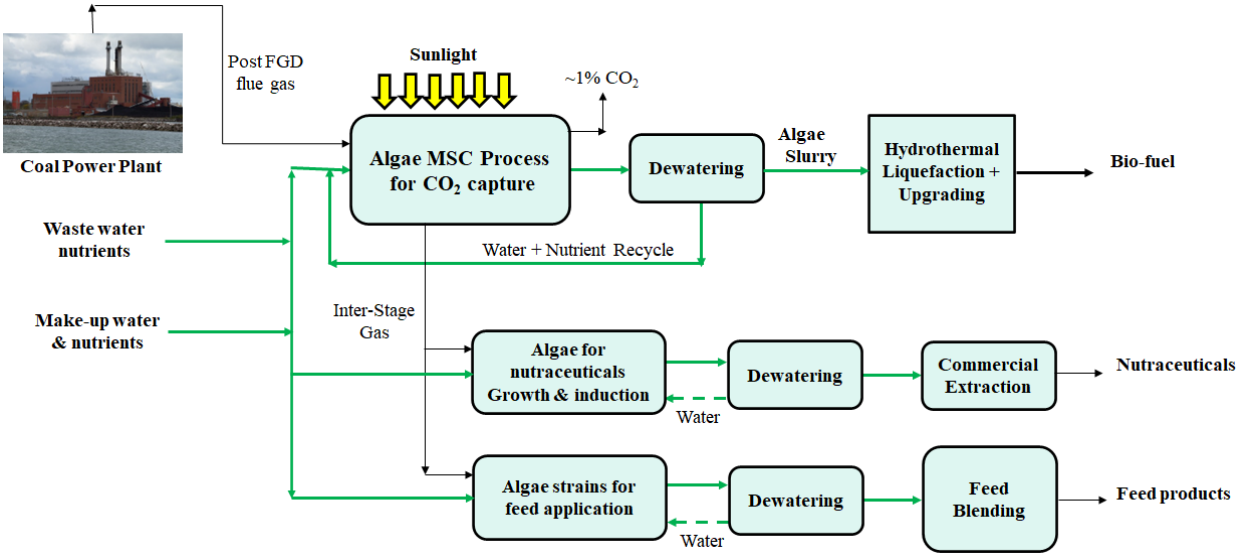

Figure 1. Envisioned Technology Schematic at Commercial Scale

CO_2 uptake from flue gas via algae in the MSC takes advantage of the inherent strengths of the organism, including:

- highest growth rate of all the photosynthetic organisms
- levels of CO_2 higher than present in the atmosphere accelerates growth
- sunlight provides the primary and sustainable energy source
- the CO_2 captured is a solid biomass - avoids gas sequestration
- noncompetitive with food crops as non-arable land can be used for cultivation
- can be acclimated to flue gas contaminants which initially inhibit growth
- wide range of components to convert into products for revenue to offset capture cost

The MSC technology features a top lit closed system which enables a predictable and controllable operation. The continuous gas and liquid flow process enables efficient upstream/downstream integration and can be tailored to applications other than coal power plants such as natural gas power plants or direct air capture. Leading up to the NCCC test, several designs of the MSC technology were tested in the laboratory (artificial light) and then the greenhouse (sunlight), prior to transition to outdoors summer operations in Western New York (WNY). During the test period of the MSC in WNY, the achievement of the project targets for algae productivity and CO_2 capture efficiencies on the simulated flue gas indicated the potential for promising results on actual flue gas at NCCC. These targets were exceeded on actual flue gas at the NCCC field test. The results demonstrate the potential of the MSC technology to capture CO_2 and produce algae for conversion to products as its development moves forward.

Project Description:

To prepare for the field test at NCCC, the work of designing, building and testing of the MSC system was conducted at Helios's facilities in Western New York. Simulated flue gas was employed for these tests (12% CO_2, SOx and NOx, and 5 heavy metals) and the MSC was weather-proofed to operate in the outdoors environment. Under the parameters of simulated flue

gas and outdoors with variable sunlight and weather during the growing season, the project goals were met for productivity of 25 grams/meter^2/day (g/m^2/d) of dried algae and 80% capture efficiency. The operational control system worked well which minimized hands-on oversight. Extended runs of the MSC demonstrated that the system was stable over time, and was ready to be tested on real flue gas in the power plant environment provided at NCCC.

Figure 2. Integrated MSC system at NCCC Bench-Scale site

Helios conducted its field test at NCCC in three parts:

June 1 - June 14, 2022	Set up
June 15 – August 30	MSC Field Test (total gas input – 900 hours)
August 31 – September 12	Breakdown

The equipment for the testing program was shipped to NCCC in early June 2022. Helios personnel along with assistance from NCCC personnel set up the algae inoculum system at the indoor laboratory site to supply seed culture to the MSC system. The MSC was set up at the bench-scale site and the utilities integrated with the system. The operational MSC is shown in Figure 2. The bench-scale site was selected for the MSC algae test due to its location on the south side of the NCCC facility where sunlight illumination was better than at other available sites. Once the inoculum was available to populate the MSC tanks, the field test began. To track the progress and function of the MSC the following value sets were recorded - average solar intensity, ambient and culture temperatures, feed gas flow rate and CO_2 concentration, liquid flow volumes, daily algae concentrations, productivity and CO_2 capture efficiency.

Test Environment and Results:

Sunlight input influences greatly the algae growth in the MSC. Figure 3 shows the recorded solar intensity in daily average lux at the NCCC test site during the field test. While many of the days were good for growing algae, >20,000 Lux/24 hours, algae growth was hampered by wide day-to-day fluctuation in average light intensity which included a number of poor growth days. As

indicated in Table 1, the average light intensity was close to the prior testing done in Western New York at the Helios outdoors testing site. Further, both the productivity and the CO_2 capture were similar between the two sites. The greater number of cloudy/rainy days than expected at NCCC particularly became a problem later in the test period when the number of days <15,000 lux/24 hours increased and the testing was terminated.

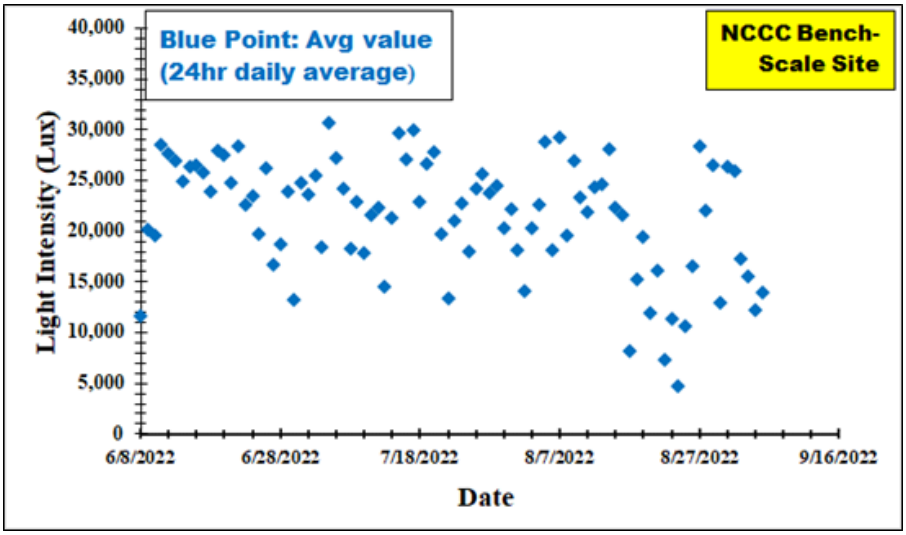

Figure 3. Daily light intensity (24 h average) per day of field test at site of MSC

NCCC provide the gas to the MSC system from their lab-scale test unit (LSTU) stream obtained from the onsite power plant post FGD flue gas. The original intent of the field test was to demonstrate the MSC on coal-based power plant flue gas post FGD which has ~12% CO_2. However, due to the power plant operations at NCCC, a blend of gas with a maintained average feed CO_2 concentration of 10.8 % (Table 1) was delivered throughout the test. The mixture in the blend varied as power generation requirements necessitated the burning of different amounts of natural gas and coal. CO_2 cylinder gas was utilized to make up the deficit to mimic 12% CO_2 flue gas when the power plant was mainly utilizing natural gas for power generation which is nominally ~6% CO_2 post FGD. Prior testing at Helios conducted with simulated flue gas (~75ppm SOx, 75ppm NOx, and 5 heavy metal contaminants of ppb concentrations) were shown to have minimal impact on MSC performance. NCCC site and other U.S. plants have scrubbers to reduce the amount of acid gases and heavy metal contaminants. Thus, high levels of these contaminants will not be a concern for the MSC performance at commercial scale in the U.S.

The objectives for the project were as follows:

- **>100 hours of continuous operation on coal plant flue gas in power plant environment**
- **80% CO_2 capture efficiency**
- **25 g/m^2/d of dried algae (100% normalized productivity)**

Table 1. Relevant test environment and operations in NCCC and WNY

	Field Test at NCCC, AL	Test at Buffalo, NY
Flue Gas	Actual Flue Gas (Coal + Nat Gas)	Simulated
Feed CO_2 Conc	10.8%	12.0%
Flue Gas Contaminant	0.4ppm SOX + 0.7ppm NOX	75 ppm SOX + 75 ppm NOX + 5 H.M
WW Nutr Replacement	N/A	80% Centr-WW
Normalized Avg Prod	123%	142%
Avg CO_2 Capture	87.2%	77.3%
Avg Light Intensity (Lux)	21,176	23,214

As summarized in Figure 4 and Table 1, the field test at NCCC in the relevant test environment resulted in a run of the MSC exceeding the project objectives – normalized productivity of 123% and CO_2 capture efficiency of 87.2%. These results are very supportive of the MSC technology to be integrated with the overall system to grow algae for carbon capture, produce products and lower the cost of carbon capture from flue gas. With the completion of the field test and the meeting of the objectives, the final step is to use the information generated to conduct Techno-Economic Analysis (TEA) and Lifecycle Assessment (LCA).

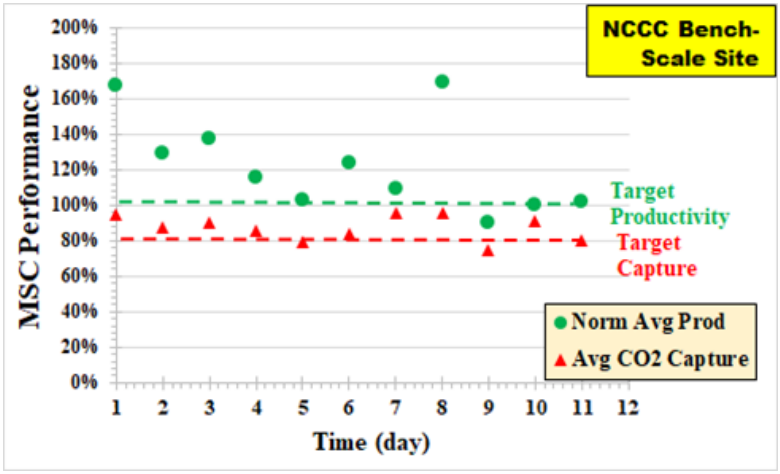

Figure 4. Test period meeting target goals in productivity and capture

Conclusions:

The following summarizes important learnings from the field test that will be used to advance the technology before significantly scaling system larger:

- **Operation on actual coal flue gas does not degrade performance**
- **Target productivity and capture efficiency achievable in field operation**
- **Tests should be done in the open free of undesirable shadowing of all or part of MSC**
  - **Lowers performance**
  - **Complicates control**
- **High ambient temperature can impact performance**

- **Larger inoculum would be beneficial in future field tests**
- **The MSC rainwater drain should be made larger for operation in areas with heavy rainfall**

The objectives of the field test project were to operate the MSC in the coal plant flue gas environment and achieve project targets for algae productivity and CO_2 capture efficiencies. Due to the power plant at NCCC only operating part of the time on coal fuel, this was only possible during the summer/winter peak electricity generation periods. Thus, for the period of time the field test was conducted, coal-based flue gas input varied from 0 to 100 % input of CO_2, the opportunity to use a significant amount of coal plant flue gas during the tests was achieved. It is noted that the acid gas level and heavy metal contaminants typically present in coal-based post FGD flue gas supplied was significantly lower at NCCC than what was used for Helios in-house tests with simulated flue gas. Since U.S. power plants operate with advanced scrubbers, adoption of the MSC technology will not interfere with its operation using this flue gas source.

The tests were periodically impaired by the poor sunlight conditions due to the weather and infrastructure shielding at the bench-scale site during the test period. The higher-than-expected ambient temperature issues were resolved with the help of the NCCC site support. Within the >900 hours of testing at NCCC, Helios executed a >100 hours continuous operations test achieving an average algae productivity of 30.7 $g/m^2/d$ and 87.2% CO_2 capture efficiency. Both of these measured values exceeded the project targets of 25 $g/m^2/d$ and 80% CO_2 capture efficiency which are important for the technology to be advanced in the future. The successful NCCC field test by Helios exceeded DOE's Bioenergy Technologies Office 2022 target productivity of $25g/m^2/day$ for algae. High algae biomass productivity coupled with conversion of algae to value-added products which creates a revenue stream, reduces the net cost of capture. The high capture efficiency of the MSC system enables comparative performance with other commercial technologies such as amines absorption and membranes, facilitating future commercial adoption.