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**Low Cost BioScrubber for
Greenhouse Gas Control**

Topical Report for Phase I
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1.0. SUMMARY AND CONCLUSIONS

The overall objective of this research program is to develop an advanced biological technology for effective and efficient recovery of greenhouse gases resulting from the production and use of fossil fuels. Physical and chemical approaches to this problem either have limited application or are costly. Recently developed biotechnologies have been playing an increasingly important role in removing pollutants from the environment. The photosynthesis reaction by various algal species using solar energy to fix CO₂ into biomass appears to be the most logical approach. However, the slow productivity of nature cannot meet the challenge from industry. Using an industrial approach to increase the biological productivity is required.

We have designed an integrated system, which has three major components: an industrial BioScrubber, a harvest system, and a biomass utilization component. The BioScrubber will be retrofitted in the power plant. A 100 MW power plant releasing 0.8 million tons of CO₂ per year will require about 50 meters cubic (50m x 50m x 50m) volume of reactor for the BioScrubber. For a 500 MW power plant, the BioScrubber requires a space of 85 meters cubic.

The primary energy requirements for the BioScrubber include that for water circulation and emission introduction, estimated to be below 0.1% of the power plant electricity. The energy production can be 800 million KWH from the biomass generated, assuming a 22% fermentation rate. In this fuel to fuel life cycle, the net gain on energy is tremendous.

The Department of Energy has set the goals of the Flue-Gas Clean-Up Program to include: 1) capturing at least 90% of the carbon dioxide, 2) constraining the increase in electricity cost to no greater than 40%, with an associated power plant efficiency penalty no greater than 15%, and 3) postponing reentry of CO₂ into the atmosphere for a period on the order of hundreds of years through innovative methods of reuse and disposal. Our approach is designed to meet all of these goals.

The objective of this Phase I study, based on the DOE's design, is to conduct a preliminary study in a short period (6 months for investigations, 2 months for report and Phase II proposal) to prove the fundamental feasibility of our concept from technical, economic, and environmental aspects.

To meet these requirements, we have designed our Phase I study to include five tasks. Task 1 is to determine if the 90% CO₂ capturing efficiency can be obtained. Task 2 is to determine if we can convert the captured CO₂ into a biomass, which can prevent the reentry of CO₂ into the atmosphere. Task 3 is to evaluate the economics to understand if the energy or cost is prohibitive.

Task 4 is to develop the Phase II work plan and Task 5 is to write final technical report of Phase I. The Phase II work plan is being submitted. The cost of Task 4 was \$4,439 and the task covered from 11/1/98 through 1/14/99. This document is a comprehensive report of the research conducted in Phase I. Task 5 ran from 12/15/98 through 1/14/00 and cost \$2,384.

The BioScrubber approach is very environmentally friendly. A National Environmental Policy Act (NEPA) questionnaire was submitted to DOE prior to the start of the project. There are no significant environmental impacts identified in this exercise. Using natural occurring algae to convert CO₂ to biomass with the natural photosynthesis reaction, indeed, is probably the most environmental friendly approach among various CO₂ mitigation alternatives.

Task 1 investigated the CO₂ capturing efficiency. Our scrubber design was verified experimentally to achieve nearly 100% CO₂ capturing efficiency, well exceeding the 90% efficiency requirements of the DOE. A conventional open pond photobioreactor has only a 20% CO₂ capturing efficiency. The closed system photobioreactor designed by RITE (Research Institute of Innovative Technology) in Japan can reach only about 50% CO₂ capturing efficiency. Our design proved to be extremely successful.

In the Task 2, we proved that we could grow algae with a media containing the CO₂ captured from the Task 1 study. We have screened a number of algal strains and identified *Chlorella vulgaris* as the fastest growing algae among those fast growing algae reported in the literature. When this alga is cultured in our culturing media using the solutions obtained from our scrubbing operation, equivalent or higher growth rate to that given in the literature can be obtained. This established the fundamental technical feasibility of our approach.

The economic feasibility is evaluated in Task 3 by comparing the parameters and economics of the commercial open system photobioreactors with our BioScrubber system. The results show that the BioScrubber can be profitable even if the alga is utilized to produce energy. If the alga is utilized for higher value applications, such as pharmaceuticals, animal food, and fertilizers, the profit margin will be greatly increased.

2.0. INTRODUCTION

The concept of CO₂ reduction using microalgae has been the subject of several prior engineering-feasibility studies. When evaluating the options for the biological recovery of CO₂, introducing it to an algal culture may be the best approach. Algae are capable of converting CO₂ into organic carbon via photosynthesis. The technology for algal mass culture is not new; microalgae mass cultures have been studied for almost 50 years, starting in the late 40's as a potential source of human food. These products (containing algal lipids, vitamins, carbohydrates, and proteins) can be used as pharmaceuticals, food supplements, animal diet enhancers, chemical products, fertilizers, and a secondary energy source. Processes for biological flue gas cleanups are still under development and there are still many economical and technological challenges. Currently, there is no practical technology available in this direction.

The concept of using outdoor macroalgal cultures in ponds, lakes, oceans or land has been proposed as a method to reduce CO₂ emissions. Although the potential of this method for CO₂ recovery has been recognized, the engineering and economical feasibilities of this approach are not fully acceptable. Since it is difficult to optimize algal growth in an open pond, the overall productivity of the process is too low. Besides, these applications would cause potential ecological problems by altering regional ecosystems. There are several commercial operations

currently producing algae with ponds. However, about 2% of the US land will have to be converted to these ponds in order to capture enough CO₂ to make a difference in the CO₂ emissions in this country. Therefore, the applicability of this approach becomes questionable.

While outdoor systems mainly struggle with low productivity, closed photobioreactors can achieve higher productivity. However, photobioreactors are still facing many technical challenges. Even though closed photobioreactors can more readily control environmental conditions (temperature, oxygen, and nutrients) than open cultures, they can not effectively control CO₂ from exhaust gases. This is caused from directly introducing CO₂ to the culture system. Because CO₂ is bubbled through the reactor to supply a carbon source for the microalgae, the excess CO₂ is emitted to the atmosphere. Another problem with directly bubbling CO₂ into the reactor arises due to the changeable CO₂ concentration and temperature, caused by combustion conditions which vary from time to time, even for the same power plant. Therefore, this is another obstacle to controlling CO₂ conditions in the photobioreactor.

In the field of closed photobioreactors, one of the leading groups is the Research Institute of Innovative Technology (RITE), who initiated a large R & D program on CO₂ mitigation technologies in the early 1990's in Japan. The RITE program has developed closed system photobioreactors using optical fibers to obtain high productivity at high light intensities.¹ However, such reactors are difficult to scale up. On top of that, their CO₂ utilization efficiency reaches only 50%.

The ultimate goal of our research program is to develop an industrial BioScrubber that can effectively and efficiently mitigate green house gases from fossil-fueled power plants. During Phase I, we focused on the study of algal growth. We optimized the major factors affecting algal growths in bench-scale cultivation. Factors like temperature, light intensity, nutrients, pH, algal cell density, algal inhibitory chemicals, and cultivation time were studied with various strains of microalgae. A study to introduce inorganic carbon to the algal culture was performed by adding (bubbling) CO₂ gas into an aqueous ammonium hydroxide solution. A preliminary economic analysis was also conducted. The results of the Phase I study are documented in this report.

3.0. INFORMATION FOR NEPA

An environmental questionnaire from DOE was completed. This document fulfills the DOE's National Environmental Policy Act (NEPA) Implementing Procedures (10CFR 1021) requirements to examine the potential environmental consequences of all proposed actions during the early planning stages. The results show that this research will not cause any significant environmental impacts. A copy of the NEPA report is attached in the Appendix.

4.0. TASK 1. ASSESSMENT OF FLUE GAS

The task was conducted from 7/24/98 through 12/31/98 with a total cost of \$13,192.

4.1. Flue Gas Composition

The United States' carbon dioxide production is on a rise from the already approximately 5.56 billion tons per year from coal-burning power plants.² This amount of CO₂ is equivalent to about 21% of the entire world's production. The flue gases' composition from power plants changes slightly with the specific fuel type and the amount of air used in combustion. Tables 4.1 and 4.2 show typical fuel and flue gas compositions with different fuel sources when air excess is approximately 10%.³ CO₂ flue gas concentrations of up to 20% have been measured when coal is burned.⁴

Table 4.1. Typical fuel compositions.

Fuel	Coal	Oil	Gas
Carbon (wt%)	66.6	87.3	72.2
Hydrogen	3.3	10.5	23.6
Sulfur	0.5	0.8	-
Nitrogen	1.4	0.3	4.2
Water	19.0	0.6	-
Ashes	9.2	0.5	-
Net Heating Value (kcal/kg)	7,000	10,000	12,000

Table 4.2. Typical flue gas compositions.

Fuel	Coal	Oil	Gas
CO ₂	15.67	12.81	8.03
CO	0.03	0.02	0.01
SO ₂	0.04	0.04	-
H ₂ O	7.63	11.78	15.06
N ₂	74.81	73.47	75.34
O ₂	1.82	1.88	1.56

The flue gas compositions emitted from coal-fired power plants were simulated following Table 4.2 for our reference material in future tasks. For the preliminary study in Phase 1, 15% (v/v) of 99% technical grade CO₂ in air was used as an inorganic carbon source for microalgae.

4.2. CO₂ Scrubbing

Our CO₂ gas scrubbing was studied during a time period of 10/1/1998 through 12/31/98.

Carbonation (CO₂ supply) is one of the most difficult processes in microalgae cultivation, yet most researchers directly inject (bubble) gaseous CO₂ into the cultivating system. Since our goal of this project is to utilize at least 90% of the CO₂ from flue gas, we attempted to handle gaseous CO₂ in advance of algal cultivation. It is known that the transfer of CO₂ through a gas-liquid interface is very slow. Significant amounts of CO₂ escape from the bioreactor before the CO₂ is dissolved into water and consumed by algae. RITE (Research Institute of Innovative

Technology) reported a 50% CO₂ utilization rate in their bioreactor. Open photobioreactor systems can use only 20% of the CO₂.⁵

In order to transfer 100% of the CO₂ into water, we have studied a CO₂ scrubber using ammonia water as a scrubbing media. A gas containing 15% CO₂ (simulated gas composition from flue gases) was bubbled into a column containing 10 liters of 5% ammonia solution. At a gas flow rate of 1 liter per minute, nearly 100% of the CO₂ was absorbed during the first 5 hours. Saturated absorption was reached at about 10 hours (Table 4.3).

Table 4.3. Efficiency of CO₂ absorption into ammonia solution.

Time (hour)	Outlet CO ₂ % (v/v)	pH
1	0	12.8
2	0	11.7
3	0	10.8
4	0	10.1
5	1.50	9.50
6	3.20	8.90
7	5.40	8.50
8	7.80	8.10
9	11.6	7.80
10	13.8	7.60
12	13.8	7.60

The ammonium carbonate solution produced from the scrubbing was later studied for cultivating microalgae. The scrubbing system has several other advantages over directly bubbling CO₂ flue gases into algal broth. Control of the exhaust gas (over 150°C) for algal cultivation is very difficult when flue gas is directly injected. In addition, ammonia can replace a regular nutrient, KNO₃, as the nitrogen source in our study. One of the advantages of using ammonia instead of nitrate is that ammonia costs much less than nitrate. Ammonium hydroxide can also replace sodium hydroxide as a pH regulator due to its low cost.

5.0. TASK 2. ASSESSMENT OF ALGAE

This task was conducted from 7/24/98 through 1/29/99 with a cost of \$27,266.

5.1. Summary

Recently, extensive considerations have been made that imply microalgae can reduce greenhouse gases, particularly CO₂ levels in the atmosphere. Since the early 1990's, the number of biotechnology studies related to CO₂ mitigation has significantly increased. To recover CO₂ out of exhaust gases from fossil fuel power plants, many methods to fixate CO₂ into photosynthetic microalgae have been tried. However, these approaches still face problems such as low productivity of the biomass and inefficient CO₂ utilization to meet industry's challenge. Unlike any other previous studies, we attempted to scrub emission gas in advance of the algal

cultivation process. With this approach, we proved a number of advantages of our system over existing processes, as described in the previous task. For this task, we wanted to determine two issues: 1) what algae grows the fastest and 2) can ammonia carbonate be the nutrient for this alga.

Algal growth studies were conducted with bench type experiments. A multi-cultivating apparatus having 50 reactors with individual internal light sources was designed and tested to screen microalgae. The effects of algal growth factors on different strains of microalgae were determined. *Chlorella vulgaris*, among five other strains of microalgae, showed the highest growth rate. Cultivating conditions for *Chlorella vulgaris* that produced the highest growth rate were at concentrations of 243 ppm CO₂, 10mM ammonia, and 1 mM phosphate, with an initial pH of 7-8.

5.2. Preliminary algal study

During the time period from 7/24/98 through 8/31/98, a literature search was conducted to select algae species with high algal growth rate for biofixing CO₂. Based on the literature evidence and previous work, three cultures (*Chlorella sorokiniana*, *Chlorella vulgaris*, and *Chlorella pyrenoidosa*) were purchased from the Carolina Biological Supply Company and the University of Texas. In addition, two Japanese cultures (*Chlorella* sp. H84 and *Chlorella sorokiniana* A-2), tolerant to high temperatures (40°C) and to high CO₂ (more than 40% CO₂ fixation),⁶ were obtained from the Research Institute of Innovative Technology for the Earth (RITE) in Japan.

The parameters chosen for our algal study were pH, dissolved oxygen, ammonia, carbon dioxide, optical density, cell density, light intensity, and temperature. In preparation to evaluate the fixation of CO₂ by microalgae, gas analyzers with CO₂ and O₂ sensors, a dissolved O₂ meter, and ion selective electrodes for sensing CO₂ and NH₃ in liquid were purchased. The instruments were tested to ensure they were appropriate for evaluating algae media and gases.

5.3. Development of a multi-cultivating apparatus

Various strains of microalgae were screened with a multi-cultivating apparatus developed in our work. This multi-cultivating apparatus is composed of 50 reactors (4L-capacity), and each reactor contains an individual fluorescent lamp (15 watts). A diagram of a single unit of the apparatus is shown in Figure 5.1. With this device, 50 different mass cultures could be conducted at a time. Since each reactor contains an internal light source, more efficient light distribution could be achieved than from a light source shining only on the surface of the cultures. The light source was driven with a programmable logic controller (PLC) for the timing sequence: the program was written in order to either 1) start a timing cycle, or 2) to override the timing cycle and go to a manual mode. Therefore, the light bulbs could be turned on and off repeatedly, and the system could be utilized to understand biomass loss and/or changes in biochemical composition of algal cells during the day and night. This work was performed during the time period of 7/24/98 through 8/31/98.

Figure 5.1. Schematic diagram of a unit photobioreactor from our multi-cultivating apparatus. The reactor has a 4L-capacity. The glass tube around the light is made of Plexiglas, so that the heat produced from the light is not transported to the algal broth.

5.4. Algal growth study

Different strains of algal cells were investigated for their cell growth studies. We initially planned to test three selected microalgae (*Chlorella vulgaris*, *Chlorella pyrenoidosa*, and *Chlorella sorokiniana*) based on the previous work and literature search, however, two more Japanese strains of algae (*Chlorella* sp. H84 and *Chlorella sorokiniana* A2) were added for comparison of their CO₂ fixation rates. Among those tested algae, *Chlorella vulgaris* showed the fastest growth rate, so the cultivating conditions for this alga were thoroughly investigated and optimized. After optimizing the culture conditions for *Chlorella vulgaris*, ammonia (for absorbing CO₂ in a CO₂ scrubbing system) was introduced to cultivate *Chlorella vulgaris* as a nitrogen source. Ammonia produced a similar *Chlorella vulgaris* growth in comparison with nitrate, which is a standard nutrient.

During our preliminary algal growth study, we measured optical density (OD) by means of counting cell population of microalgae with a UV/Vis Spectrophotometer at 680 nm. Figure 5.2 shows a linear relationship between optical density and cell density (cells/mL).

Figure 5.2. A linear relationship between optical density and cell density.

5.4.1. Algae Selection and Testing

During the time period from 9/1/98 through 11/30/98, CO₂ fixation rates of the following green microalgae were determined: *Chlorella* sp. H84, *Chlorella sorokiniana* A-2, *Chlorella vulgaris*, *Chlorella pyrenoidosa*, and *Chlorella sorokiniana*.

Experimental

Medium and cultivation conditions: *Chlorella* sp. H84 (H84) and *Chlorella sorokiniana* A2 (A2) were obtained from the Research Institute of Innovative Technology for the Earth (Tokyo, Japan). Although most organisms cannot survive under high temperatures, certain kinds of microalgae such as H84 and A2 can thrive in Hot Springs. Their tolerance to high temperature could be beneficial to the biological CO₂ fixation, since the flue gas from power plants is about 40°C after desulfurization and nitrogen oxide removal. MC medium⁴ was used for cultivating both algae. MC medium was composed of (g.L⁻¹) KNO₃, 1.25; KH₂PO₄, 1.25; MgSO₄·7H₂O, 1.25; Fe solution, 1 mL; A5 solution (composed of H₃BO₃, MnSO₄·4H₂O, ZnSO₄·7H₂O, CuSO₄·5H₂O, Na₂MoO₄·2H₂O, H₂O), 1 mL. They were pre-cultured and then mass cultured in a warm water bath at a temperature of 40°C as recommended by Sakai et al.¹ Inorganic carbon was a carbonate solution prepared by a mixture of CO₂ gas and ammonium hydroxide (NH₄OH) solution.

ASM-1 Medium⁷ for *Chlorella pyrenoidosa* and *Chlorella sorokiniana* and N-8 medium⁸ for *Chlorella vulgaris* were used. ASM-1 medium was composed of (g.L⁻¹) Na₂HPO₄·2H₂O, 0.26; KH₂PO₄, 0.740; CaCl₂, 0.01; FeEDTA, 0.01; MgSO₄·7H₂O, 0.05; KNO₃, 1.0; and trace element stock solution, 1.0 mL/L. N-8 medium was composed of (g.L⁻¹) NaNO₃, 0.17; MgSO₄·7H₂O, 0.024; MgCl₂, 0.019; CaCl₂, 0.022; K₂HPO₄, 0.017; Na₂HPO₄, 0.014; and trace element stock solution, 1.0 mL/L. Cells were activated by inoculating a loop of a slant culture into 100 mL of the medium in a 250-mL Erlenmeyer flask and were precultured under continuous illumination at room temperature (20-25°C) for a week. Four fluorescent lamps (Econ-F40LW/RS/EW, 34 Watt, Philips, Underwriters Laboratories Inc.) were used as the light source. CO₂ mixed in air was supplied to the cultures through an air diffuser (Aqua-Tech, Moorpark, CA).⁷

Analytical methods: The light intensity was measured by an analog photometer. The optical density of the cell was measured by a UV/VIS spectrophotometer (Lambda 3B, Perkin Elmer) at 680 nm. The pH levels of the cultivated solutions were measured by an Accumet 925 pH/ion Meter (Fisher Scientific) and adjusted with 1M HCL and 1M NaOH.

Results and Discussion

Growth characteristics for H84 and A2: H84 and A2 strains did not show any great change on cell growth over a time period of six to nine days in the temperature range of 25-40°C. It was, however, decided not to optimize the cultivation conditions for these strains due to different ecology between Japan and the United States.

Growth characteristics of *Chlorella sorokiniana*: The cell density of *Chlorella sorokiniana* at the beginning was 3.5×10^5 . The algal growth rate was investigated at different pH's, 7.0, 7.9 and 9.4. The light intensity was 200 ft. Candle and a 20% mixture of CO_2 in air was added to the cultures. Very slow growth of this alga was obtained. Table 5.1 shows both the cell density and the optical density (OD) of the *Chlorella sorokiniana* at different pH's.

Table 5.1. Growth of *Chlorella sorokiniana*.

pH	Cell density ($\times 10^5$)			Optical density		
	Day1	Day2	Day5	Day1	Day2	Day5
7.0	3.5	4.5	6.1	0.066	0.069	0.340
7.9	3.5	3.0	7.5	0.066	0.065	0.308
9.4	3.5	2.1	13.5	0.056	0.056	0.160

Growth characteristics of *Chlorella pyrenoidosa*: *Chlorella pyrenoidosa* was cultured at two different CO_2 concentrations, 16% (v/v) and 20% (v/v) in air by bubbling CO_2 directly into broth. Different light intensities (200 ft. Candle and 400 ft. Candle) were also tested with this algal culture. Under these conditions, *Chlorella pyrenoidosa* was dead after several days. Optimum cultivating conditions were determined for *Chlorella pyrenoidosa* by using inorganic salts as a carbon source instead of directly bubbling CO_2 through the algal medium. 7.63 ppm of CO_2 (as NaHCO_3), 1 mM of ammonia and 0.5 mM of phosphate were found to be optimum concentrations.

Growth characteristics of *Chlorella vulgaris*: The optimum starting cell density for *Chlorella vulgaris* was investigated (Figure 5.3). With the cell density of 1.775×10^3 (cells/mL), *Chlorella vulgaris* grew very slowly. At the range of 1.775×10^4 to 10^5 cells, *Chlorella vulgaris* grew faster than with the lower initial cell density. Therefore, all cultivation of the alga was started at or above these cell densities.

Figure 5.3. *Chlorella vulgaris* growth with different starting cell densities.

Figure 5.4 explains the *Chlorella vulgaris* growth rate with different concentrations of CO₂. Without any addition of CO₂, *Chlorella vulgaris* grows very slowly, due to low concentration of CO₂ (0.035%) in air. Both 10% (v/v) and 20% (v/v) of CO₂ showed similar results. With 30% (v/v) of CO₂ in air, the growth rate was higher after four days than the growth rate obtained under the other conditions.

Figure 5.4. *Chlorella vulgaris* growth with different CO₂ concentration (vol %) in air.

5.4.2. Optimizing Culture Conditions of *Chlorella vulgaris*

Chlorella vulgaris has been used for mass cultures of algae for decades. It produces a range of high-value substances, and the biomass itself is used in aquaculture for feeding purposes and as an additive for animal feed that is rich in vitamins.^{9, 10} *Chlorella vulgaris*, among five other strains of microalgae, showed the highest growth rate in our study. *Chlorella vulgaris*, therefore, was selected and studied as our primary candidate for BioScrubber system in our current work.

Experimental

Culture medium and conditions: A tablet composed of tartaric acid and sodium bicarbonate was used as the carbon source for *Chlorella vulgaris*. Various amounts of bicarbonate salt, sodium hydrogen phosphate, and ammonium hydroxide were dissolved in a 250-mL Erlenmeyer flask with 100-mL of N8 medium (not including P and N sources). Approximately 3 to 5 mL of pre-cultured algal broth were added to the Erlenmeyer flask to produce a range of a 0.07 to a 0.10 initial optical density. The pH of each algal broth was adjusted with 1M of HCl, NaOH and/or NH₄OH. *Chlorella vulgaris* was cultivated under continuous illumination at room temperature (20 - 24°C) for 5 to 6 days with the light intensity of 400 ft. Candle.

Results and Discussion

Growth characteristics for *Chlorella vulgaris*: In order to optimize the cultivation conditions for *Chlorella vulgaris*, first, an optimum CO_2 concentration was investigated using CO_2 tablets. The CO_2 tablet, composed of sodium bicarbonate and tartaric acid, evolved CO_2 gas when placed in water. At a concentration of 242.7 ppm of carbon dioxide (equivalent to 15.3 ppm as bicarbonate), the *Chlorella vulgaris* strain exhibited its highest growth rate (Figure 5.5).

Figure 5.5. The optimum concentration of CO_2 was investigated for the *Chlorella vulgaris* culture. The legends describe the CO_2 concentration as sodium bicarbonate (NaHCO_3), ppm.

At the optimum concentration of CO_2 , concentrations of other species in the algal broth were calculated by a software program, called MINEQL^{4.0} (calculation program based on thermodynamics). It was found that at the conditions of pH 5.7 and 242.7 ppm of CO_2 , the algal broth contains 4.61×10^{-3} M of aqueous carbon dioxide (H_2CO_3) and 8.92×10^{-4} M of bicarbonate (HCO_3^-) (Figure 5.6). This indicates that *Chlorella vulgaris* can utilize both aqueous carbon dioxide (ca. 80%) and bicarbonate (ca. 20%) for its biological CO_2 fixation.

Figure 5.6. The MINEQL4.0 program shows the concentrations of carbonate species existing in the algal broth at a pH of 5.6 and 242.7 ppm of carbon dioxide.

The effects of nitrogen (N) and phosphorus (P) sources on *Chlorella vulgaris* were investigated. *Chlorella vulgaris* grew better and faster with N-8 medium containing both N and P than without them (Figure 5.7). The optimum concentrations of phosphate and ammonia were determined for *Chlorella vulgaris* at the optimized CO₂ level. Similar *Chlorella vulgaris* growth was obtained with both ammonium ion and nitrate ion for a nitrogen source (Table 5.2). It was, therefore, decided to use ammonium hydroxide (NH₄OH) as the nitrogen source for all *Chlorella vulgaris* cultures, since NH₄OH is much less expensive than nitrate (KNO₃). The price of technical grade KNO₃ is \$545/ton, while high purity ammonia is only \$209/ton. In addition, six tons of KNO₃ are needed to provide the same amount of nitrogen as from one ton of ammonia.

Figure 5.7. The effects of nitrate and phosphate ions on a *Chlorella vulgaris* culture at an optimized CO₂ concentration.

Table 5.2. Cell growth of *Chlorella vulgaris* with two different sources of nitrogen, ammonia and nitrate.

Source of Nitrogen	Cell Density (cells/mL)
Ammonia	4.0×10^6
Nitrate	3.8×10^6

The highest cell growth of *Chlorella vulgaris* was achieved with 10 mM of ammonia and 1 mM of phosphate (Figures 5.8 and 5.9).

Figure 5.8. Optimizing ammonia concentration for a *Chlorella vulgaris* culture. The legend indicates the concentration of ammonia as Molarity (M).

Figure 5.9. Optimizing phosphate concentration for a *Chlorella vulgaris* culture. The legend indicates the concentration of phosphate as milli Molarity (mM.).

With 10 mM of ammonia and 1 mM of phosphate, the growth of *Chlorella vulgaris* was the highest. There was a great incremental increase in optical density between day 4 and 5, while other cultures showed slow growth. A very high concentration of ammonia and phosphate appeared to inhibit the *Chlorella vulgaris* growth.

6.0. TASK 3. PRELIMINARY COST ESTIMATION

Since the development of BioScrubber is still in an early stage, it is not possible to conduct a direct cost estimation at this moment. The overall economics can only be estimated on the basis of existing algal cultivation activities. This task ran from 10/1/98 through 12/31/98 at a cost of \$2,334.

The 1996 report of Benemann⁵ has documented the cost for open pond photobioreactors. Commercial operations for these reactors include the wastewater treatment plants and the growth of *Chlorella* (in Far East), *Spirulina* (in Mexico), and *Dunaliella* (in Australia). Market values for *Chlorella*, *Spirulina*, and *Dunaliella* are \$30,000, \$25,000, and \$600,000 per ton, respectively.

Table 6.1 summarizes the cost and economics for algae culturing in an open pond with low value application (energy production) in mind. Total capital cost is \$100,000 per ha (hectare) for a 30 cm deep pond. The algal productivity is projected at 30 g/m²/day. The direct operating cost is \$10,000/ha/yr. Total production of the algae per year is 109 mt/ha/yr.

The open pond system can only use the sunlight coming to the surface of the water. Therefore, all the calculations are based on the area of the pond. For a BioScrubber or other closed system photobioreactor, sunlight is directed into the reactor and consequently the calculation will be based on the total volume. To compare the two systems, we will have to convert the open pond system to a volume-based reactor (see Table 6.2). For an open pond with 30-cm water depth, one hectare would contain 3,000 m³ water. The annual productivity of 109 mt/ha/yr would be converted to 0.0363 mt/m³/yr.

In a BioScrubber system, algal productivity at 0.3 g/L/Hr⁹ can be achieved. This is equivalent to 2.63 mt/m³/yr. Therefore, we have productivity increasing by 72 times.

Using a closed system bioreactor will result in increased capital cost. Benemann estimated that the cost increase would be about five times that of the open system.

The operating cost will be about the same for water pumping and labor, but will be increased by 72 times for nutrient if the same nutrient is utilized in the closed system. Nutrient cost is about 1/8 of the operation cost, as estimated by Benemann. Therefore, the operating cost in the closed system would be about 10 times of the open system.

Biomass can be utilized to produce methane gas and oil. This will be the revenue for the operation. The amount of gas and oil production will be direct proportional to the amount of biomass generated.

When all of the cost and revenue are estimated, the open pond system will cost \$73 to mitigate a ton of CO₂. However, the BioScrubber is estimated to generate \$41 profit to mitigate a ton of CO₂.

The \$25/barrel oil revenue utilized by Benemann could be an optimistic number comparing to the current price of oil, which is only about half of this. However, this will not

change the conclusion that BioScrubber can be a profitable operation except that the profit will be reduced to \$3 for each ton of CO₂ mitigated. If the biomass is utilized for higher value applications than energy, the profit will be greatly increased.

Table 6.1. Summary of microalgae capital and operating costs (from Benemann, 1996).

PRODUCTIVITY ASSUMED: <i>(ash-free dry weight)</i>	Currently Projected
Average daily g/m ³ /day	30
Annual mt/ha/yr	109
Barrels of oil/ha/yr	380
CO ₂ fixed into Biomass mt/ha/yr	240
CAPITAL COST (\$/ha):	
Ponds (earthworks, CO ₂ sumps, mixing)	27,500
Harvesting (settling ponds, centrifuges)	12,500
System-wide costs (water, CO ₂ supply, etc.)	30,000
Processing (oil extraction, digestion)	10,000
Engineering, Contingencies (25% of above)	20,000
TOTAL CAPITAL COSTS (\$/ha)	100,000
OPERATING COSTS (\$/ha/yr):	
Direct costs (Power, nutrients, labor, OH, etc.)	10,000
Annualized capital costs (0.2x total capital)	20,000
Credit for methane produced	-3,000
Credit for oil produced (\$25/barrel)	-9,500
Net operating costs \$/ha/yr	17,500
CO₂ mitigation costs (\$/mt CO₂ fixed into oil)	73

Table 6.2 Preliminary Economic Estimation of BioScrubber.

Parameters	Open Pond		BioScrubber
	by Area	by Volume	by Volume
Productivity			
Biomass	109 mt/ha/yr	0.0363mt/m ³ /yr	2.63 mt/m ³ /yr
CO ₂ Fixed	240 mt/ha/yr	0.08 mt/m ³ /yr	5.76 mt/m ³ /yr
Oil Production	380 barrel/ha/yr	0.127 barrel/m ³ /yr	9.12 barrel/m ³ /yr
Capital Cost	\$100,000/ha	\$33/m ³	\$165/m ³
Operation Cost	\$10,000/ha/yr	\$3.3/m ³ /yr	\$33/m ³ /yr
Annualized Capital Cost (0.2 x Total Capital Cost)	\$20,000/ha	\$6.6/m ³ /yr	\$33.3/m ³ /yr
Total Cost	\$30,000/ha/yr	\$9.9/m ³ /yr	\$66.3/m ³ /yr
Revenue for Methane Produced	\$3,000/ha	\$1.0/m ³ /yr	\$72/m ³ /yr
Revenue for Oil Produced (\$25/barrel)	\$9,500/ha	\$3.2/m ³ /yr	\$230.4/m ³ /yr
Total Revenue	\$12,500/ha	\$4.2/m ³ /yr	\$302.4/m ³ /yr
Net Profit	-\$17,500/ha	-\$5.7/m ³ /yr	\$236.1/m ³ /yr
Net CO₂ mitigation (per ton)	-\$73/ton	-\$7.3/ton	\$41/ton

Reference:

- ¹ Nishikawa, N., et al., Amsterdam Meeting 1992.
- ² Apel, W. A.; Walton, M. R.; Dugan, P. R., Fuel Processing Technology, 1994, 40, 139.
- ³ Mustacchi, C.; Armenante, P.; Cena, V., "Carbon Dioxide Disposal in the Ocean," Carbon dioxide, Climate, and society: Proceedings of a IIASA Workshop, Williams, J. (ed), 1978, pp 283-289.
- ⁴ Saki, N.; Sakamoto, Y.; Kishimoto, N.; Chihara, M.; Karube, I., "Chlorella Strains From Springs Tolerant to High Temperature and High CO₂," International Marine Biotechnology Conference, 1994.
- ⁵ Benemann, J. R.; Oswald, W. J., "Systems and Economic Analysis of Microalgae Ponds for Conversion of CO₂ to Biomass," Final Report to the Department of Energy, Report No. DE-FG22-93PC93204, 1996.
- ⁶ Sakai, N.; Sakamoto, Y.; Kishimoto, N.; Chihara, M.; Karube, I. Unpublished study.
- ⁷ Apel, W. A.; Walton, M. R.; Dugan, P. R., Fuel Processing Technology, 40, 1994, 139.
- ⁸ Javanmardian, P.; Palsson, B. O., High-Density Photoautotrophic Algal Cultures, Biotechnology and Bioengineering, 38, 1991, pp 1182-1989.
- ⁹ De Pauw N. and Persoone G., Micro-algae for aquaculture. In: Borowitzka L.J. (eds), Micro-algal biotechnology. Cambridge University Press, Cambridge, 1988, pp 197-221.
- ¹⁰ Becker, E. W., Micro-algae for human and animal consumption. In: Borowitzka, M. A. and Borowitzka, L. J. (eds.), Micro-algal biotechnology. Cambridge University Press, Cambridge, 1988, pp 153-196.

APPENDIX
NEPA QUESTIONNAIRE

ENVIRONMENTAL QUESTIONNAIRE

I. BACKGROUND

The Department of Energy's (DOE) National Environmental Policy Act (NEPA) Implementing Procedures (10 CFR 1021) require careful consideration of the potential environmental consequences of all proposed actions during the early planning stages. DOE must determine at the earliest possible time whether such actions require either an Environmental Assessment or an Environmental Impact Statement, or whether they qualify for Categorical Exclusion. To comply with these requirements, an Environmental Questionnaire must be completed for each proposed action to provide DOE with the information necessary to determine the appropriate level of NEPA review.

II. INSTRUCTIONS

Separate copies of this Environmental Questionnaire should be completed by the principal offeror and each proposed subcontractor. In addition, if the proposed project includes activities at different locations, an independent questionnaire should be prepared for each location. Supporting information can be provided as attachments.

In completing this Questionnaire, the proposer is requested to provide specific quantities regarding air emissions, wastewater discharges, solid wastes, etc., to facilitate the necessary review. In addition, the proposer should identify the exact location of the project and specifically describe the activities that would occur at that location.

To expedite completion of this questionnaire, diskette copies in WordPerfect 5.1 are available upon request. Questions regarding the type of information requested or the approach to preparing responses should be referred to Lloyd Lorenz, U.S. Department of Energy, Federal Energy Technology Center, by phone (412) 892-5159, fax (412) 892-5127, or E-mail (llorenz@fec.doe.gov).

III. QUESTIONNAIREA. PROJECT SUMMARY

1. Solicitation Number:	DE-RA26-98FT35008 (PRDA#)	-98FT40414
2. Proposer & all Proposed Subcontractors:	Michigan Technological University	
3. Principal Investigator:	Dr. J.Y. Hwang	
Telephone Number:	906/487-2600	
4. Project Title:	Low Cost BioScrubber for Greenhouse Gas Control	
5. Duration:	5 years 6 months	
6. Location (city/township, county, state):	Houghton, Houghton County, Michigan	

Indicate the type or scale of project:

a. ☐ Computer Modeling	b. ☐ Library/Literature Search
c. ☐ Paper Study	d. ☐ Workshop/Conference
e. ☒ Laboratory (Batch) Research	f. ☒ Bench-scale Research
g. ☐ Pilot- or Proof-of-Concept-Scale Research	h. ☐ Pilot Plant Construction/Operation
i. ☐ Full-scale Demonstration	j. ☐ Other (please describe)

If neither item d, e, f, or i was selected for Question A.7, proceed to Section IV. CERTIFICATION BY PROPOSER. Submission of the intervening parts of this Questionnaire is not required.

However, if either item d, e, f, or i was selected, continue with Question A.8.

8. Indicate the size of the proposed project and the primary material processed (e.g., 200 tph of coal)

_____	tph (of _____)	_____	MM Btu/hr
_____	scfm (of _____)	_____	MW ☐ electric ☐ thermal
_____	acfm (of _____)	<u>X</u>	Other: <u>characterization, lab batch</u>

9a. Summarize the proposed work. List all activities or tasks planned at the location covered by this Environmental Questionnaire.

Laboratory and bench scale testing of a CO₂ BioScrubber and associated analytical work.

9b. Characterize the work site at this location (check all that apply).

☒ Existing Building (indoors) ☐ Developed site ☐ Undeveloped site

10. List all other locations where work would be performed. (Note: Submit a separate Environmental Questionnaire for each location.)

All work is being performed at the Institute of Materials Processing at Michigan Technological University. A potential demonstration site is undetermined at this time.

11. Describe the objectives of the proposed project.

The objectives of the proposed project are to reduce and recover greenhouse gases resulting from the production and use of fossil fuels.

12. Identify the planned number of tests, the frequency of testing (e.g., tests per week), and the duration of tests by type (e.g., laboratory tests, pilot unit runs, etc.).

13. Identify all materials that would be used and produced by the project (materials can be grouped by category) and estimate their total quantities over the entire duration of the proposed project.

Materials Used (total quantity)		Materials Produced (total quantity)	
☐ coal	_____	☐ wastewater	_____
☐ natural gas	_____	☐ air emissions	_____
☐ oil	_____	☐ solid waste	_____
☐ electricity	_____	☐ hazardous waste	_____
☐ water	_____	☐ saleable by-products --	_____
☐ air	_____	list and note quantity	
☐ organic solvents	_____		
☐ others -- list and note quantity		☐ others -- list and note quantity	
☐ None		☐ None	

B. PROPOSED PROJECT AND ITS ALTERNATIVES

1. List all alternative approaches considered to achieve the objectives described in A.1.1 and discuss the anticipated environmental effects of each. (Place the selected approach at the top of the list.)

Laboratory bioscrubber experiments - no environmental impact.

Other approaches would not meet objectives.

2. Identify the environmental consequences of not implementing this project (e.g., emission increase).

Emissions would remain constant or increase because the technology we are developing would reduce emissions.

C. PROJECT LOCATION

1. Provide a brief description of the project location (physical location, surrounding area, adjacent structures).

This project will be conducted at the Institute of Materials Processing (IMP), located in the Minerals and Materials Engineering Building (M&M) on the campus of Michigan Technological University in Houghton, Michigan.

2. Attach a site plan or topographic map of the area that would be affected by the project and highlight (or otherwise identify) the specific location where the project would be performed.

The project will be performed in Building #12 on the attached campus location map.

D. ENVIRONMENTAL IMPACTS

This section is designed to obtain information for objectively assessing the environmental impacts of a proposed project. NEPA procedures require evaluations of all possible effects (including: land use, energy requirements, natural or depletable resource use, historic and cultural resources, and pollutants) from proposed projects on the environment. Answer the following questions as completely as possible. Also, for "yes" or "no" questions, answer "yes" if there would be any effect, or if there may be an effect. (Failure to answer the questions completely could produce delays in project awards.)

1. Land Use

- a. Identify the location of the proposed project (i.e., city, county, state):

Houghton, Houghton County, Michigan

- b. Identify the total size of the facility and the portion would be used for the proposed project.

The total size of the research portion of the M&M building is 87,950 assignable square feet. IMP occupies 23,955 assignable square feet, or 27% of the building. The project will utilize approximately 30% of IMP's space.

- c. Characterize present land use where the proposed project would be located.

☐ Urban	☐ Industrial
☐ Commercial	☐ Agricultural
☐ Suburban	☐ Rural
☐ Residential	☒ Research Facility
☐ Forest	☒ University Campus
☐ Other	

LOCATION MAP

PORTAGE LAKE

MICHIGAN TECHNOLOGICAL UNIVERSITY
HOUGHTON, MICHIGAN

BUILDING NUMBERS

- 1 Administration and Student Services
- 2 ROTC
- 3 Academic Office
- 4 Electrical Energy Resource Center
- 5 Alumni House/Michigan Tech Fund
- 6 Inter Arts and Humanities Center
- 7 Undergraduate and Materials Engineering
- 8 Counseling Services
- 9 Oldman (Civil-Geology)
- 10 Power Hall
- 11 Lib. for Pre Lib.
- 12 Forestry/Institute of Wood Research
- 13 Chemical Science & Engineering
- 14 H.L. Smith Mechanical Engineering/Engineering Mechanics
- 15 Student Development Center
- 16 Douglas Houghton Hall
- 17 Douglas Houghton Apartments
- 18 Manning Union
- 19 Anderson Hall
- 20 Amy McGee Hall
- 21 McGee Food Service
- 22 First Judicial Hall
- 23 Central Heating Plant
- 24 Facilities Management Storage
- 25 Geology Laboratory
- 26 Storage Service (Food Cans)
- 27 Gates House Center
- 28 U.S. Forest Engineering Laboratory

d. Describe how land use would be affected by planned construction activities.

☒ No construction would be anticipated for this project.

e. Describe how land use would be affected by operational activities associated with the proposed project.

Land use would not be affected.

f. Describe any plans to reclaim and/or revegetate areas that would be affected by the proposed project.

☒ No land areas would be affected ☐ None

g. Would changes resulting from the proposed project affect future uses of the site or surrounding areas?

☒ No ☐ Yes (describe)

h. Would the proposed project affect any unique or unusual landforms (e.g., cliffs, waterfalls, etc.)?

☒ No ☐ Yes (describe)

i. Would the proposed project affect existing or future recreational opportunities in the area?

☒ No ☐ Yes (describe)

j. Would the proposed project be located in or near a national park or wilderness area?

☐ No ☒ Yes (describe)

Keweenaw National Historic Park

If the project would involve only laboratory or bench-scale research and be conducted within an existing building, proceed to Part D.8 (Atmospheric Conditions/Air Quality). If the project would be larger than bench-scale, continue with Part D.2.

2. Construction Activities and/or Operation

a. Describe the topography at the project site, including any significant landforms, etc.

b. Identify any transmission lines and/or pipelines that traverse the proposed site and clearly mark them on the site plan or topographic map.

☐ None

c. Would the proposed project require the construction of settling ponds?

☐ No ☐ Yes (describe, identify location, and estimate surface area disturbed)

d. Would the proposed project affect any existing dry or wetland?

☐ No ☐ Yes (describe)

e. Would the proposed project be located in or impact a floodplain?

☐ No ☐ Yes (describe)

f. Would the proposed project be located on (or near) or impact wetlands?

☐ No ☐ Yes (describe)

g. Would the proposed project be likely to cause erosion?

☐ No ☐ Yes (describe)

h. Would any wetlands be impacted by the discharge of wastewater from project activities?

☐ No ☐ Yes (describe)

i. Would any construction activities planned under the proposed project result in stream diversion?

☐ No planned construction ☐ No ☐ Yes (describe)

3. Geological/Soil Conditions

a. Describe any instability (e.g., subsidence) in the topography near the proposed project.

b. Is there faulting in the vicinity of the proposed project area?

☐ No ☐ Yes (describe)

c. Describe the soil in the vicinity of the proposed project in terms of productivity, presence of unique species, and susceptibility to erosion.

d. Would any construction activities planned under the proposed project result in subsidence or changes in soil permeability/filtration?

☐ No planned construction ☐ No ☐ Yes (describe)

4. Vegetation and Wildlife Resources

a. Describe the indigenous flora and fauna in the vicinity of the proposed project.

b. Identify any state- or Federal-listed endangered or threatened species in the vicinity of the proposed project.

☐ None

c. Would any threatened or endangered species or their habitat be affected by the proposed project?

☐ No ☐ Yes (describe)

d. Describe any impacts that construction would have on sensitive or unique habitats.

☐ No planned construction ☐ No habitats ☐ None (discuss) ☐ Impact (describe)

e. Would any species or subspecies, not indigenous to the area, be introduced as a result of the project (e.g., introducing a new bacterial strain, as in microbial desulfurization projects)?

☐ No ☐ Yes (describe)

f. Would any migratory corridors be impacted or disrupted by the proposed project?

☐ No ☐ Yes (describe)

g. What regulatory authority maintains cognizance over indigenous wildlife species?

5. Socioeconomic and Infrastructure Conditions

a. What is the population in the vicinity of the proposed project and in communities near the project site?

b. Describe employment and labor mix in the vicinity of the proposed project.

c. Would changes (increases/decreases) in regional labor requirements be created by the proposed project?

☐ No ☐ Yes (describe)

d. Would the proposed project alter present traffic patterns?

☐ No ☐ Yes (describe)

e. Would the proposed project require new transportation access (roads, rail, etc.)?

☐ No ☐ Yes (describe)

f. Would the proposed project create an increase in local energy usage?

☐ No ☐ Yes (describe)

g. Would the proposed project increase local energy efficiency?

☐ No ☐ Yes (describe)

h. Would the proposed project significantly impact local fuel or energy supply?

☐ No ☐ Yes (describe)

i. Would any new transmission lines be required?

☐ No ☐ Yes (describe location, voltage, and length of line)

6. Historical/Cultural Resources

a. Describe any historical or cultural places in the vicinity of the proposed project; note any sites included on the National Register of Historic Places.

☐ None ☐ The following historical/cultural places are located in the project area:

b. Are there any known archeological sites in the vicinity of the proposed project?

☐ No ☐ Yes (describe)

c. Would construction or operational activities planned under the proposed project disturb any historical or cultural sites?

☐ No planned construction ☐ No historic sites ☐ No impact (discuss) ☐ Yes (describe)

d. Has the State Historic Preservation Office been contacted with regard to this project?

☐ No ☐ Yes (describe)

7. Visual Resources

a. Describe any scenic vistas or aesthetic landscaping in the vicinity of the proposed project?

☐ None ☐ The following visual resources exist in the project area:

b. Would the proposed project interfere with visual resources (e.g., eliminate scenic views) or alter the present landscape?

☐ No ☐ Yes (describe)

c. Would any facilities constructed under the proposed project contrast with the present landscape?

☐ No construction planned ☐ No ☐ Yes (describe)

For all proposed projects involving secondary bench-scale or larger research and development activities, respond to the following questions

8. Atmospheric Conditions/Air Quality

a. Describe the local climate.

Very seasonal, average temperature of 40°F, average snowfall of 200-250".

b. Identify air quality conditions in the immediate vicinity of the proposed project with regard to attainment of National Ambient Air Quality Standards. (This information should be available from the county environmental agency.)

	Attainment	Non-Attainment
O ₃	☒	☐
SO _x	☒	☐
PM ₁₀	☒	☐
CO	☒	☐
NO ₂	☒	☐
Lead	☒	☐

c. Would the proposed project be in compliance with the National Emissions Standards for Hazardous Air Pollutants?

☐ No (explain) ☒ Yes

d. Would the proposed project be classified as either a New Source or a major modification to an existing source?

☒ No ☐ Yes (describe)

e. Would the proposed project be in compliance with the New Source Performance Standards?

☒ Not applicable ☐ No (explain) ☐ Yes

f. Would the proposed project be subject to prevention of significant determination review?

☒ Not applicable ☐ No (explain) ☐ Yes (describe)

g. What authority regulates air quality in the project area (identify Federal, state, and local authorities)?

EPA

Michigan Department of Environmental Quality Air Quality Division

h. Identify the contact person, address, and telephone number for each authority.

EPA Region 5, 812-886-1424

MDEQ AQD, Marquette District, 906-228-6561

i. When were these authorities contacted regarding the proposed project (if necessary)? Include results of discussions.

☒ Not contacted

How does each regulator (authority) define a major source (e.g., greater than 100 ton/year thermal input or 150 MMBtu/hr)?

Greater than: 100 ton/year CO, 40 tpy NOX, 40 tpy SO₂, 25 tpy PM, 15 tpy PM₁₀, 10 tpy VOC, + 0.6 tpy lead.

j. Would any types of emission control or particulate collection devices be used?

☒ No ☐ Yes (describe, including location of devices)

l. If no control devices are used, how would emissions be vented?

There are no emissions anticipated.

m. What types of air emissions, including fugitive emissions, would be anticipated from the proposed project, and what would be the total quantity and maximum annual rate of emissions over the duration of the project?

☒ None	(Maximum per year)	(Total for project)
☐ SO _x		
☐ NO _x		
☐ PM ₁₀		
☐ CO		
☐ Lead		
☐ H ₂ S		
☐ organic solvent vapors or other volatile organic compounds - list		
☐ hazardous air pollutants - list		
☐ other - list		

n. Would the proposed project reduce the amount of air emissions in the area?

☒ No ☐ Yes (describe)

o. Identify Federal, state, and local air quality regulations that govern emissions in the project area.

Clean Air Act Amendments, National Ambient Air Quality Standards,
Natural Resources & Environmental Protection Act

9. Hydrologic Conditions/Water Quality

a. What is the closest body of water to the proposed project area and what is its distance from the project site? Indicate on the site plan, if provided.

Portage Lake, approximately 100 ft.

b. What sources would supply potable and process water for the proposed project? Identify quantities consumed and uses. Identify the names of municipal or other water systems that would be used.

City of Houghton

c. Quantify the total amount of wastewater that would be generated by the proposed project.

☐	None	
☐	non-contact cooling water	gallons:
☐	process water	gallons:
☒	sanitary and/or grey water	gallons:
☐	other - describe	gallons:

d. What would be the components of such effluent wastewater (e.g., how does it)?

From washing glassware - detergent.

e. Identify the local treatment facility that would receive wastewater from the proposed project.

☐ No discharges to local treatment facility.

Portage Lake Waste Water Treatment Plant

f. Describe how wastewater would be collected and treated.

Standard municipal treatment methods.

g. What Federal, state, and local authorities regulate water quality in the proposed project area?

Michigan Department of Environmental Quality, United States Coast Guard

h. Identify the contact person, address, and telephone number for each authority.

Jack Ryquist, MDEQ - 906-228-6561, Coast Guard - 906-482-1520

i. When were these authorities contacted regarding the proposed project (if necessary)? Include results of discussions.

☒ Not contacted

j. Would any run-off or leachates be produced from storage piles or waste disposal sites?

☒ No ☐ Yes (describe sources, nature of flow, and collection techniques)

k. Identify Federal, state, and local regulations that govern water effluents/water quality in the project area.

Clean Water Act, Michigan Water Resources Commission Act, Michigan Mineral Well Act, Safe Drinking Water Act (Groundwater Provisions), Michigan Great Lakes Protection Act

l. Where would wastewater effluents from the proposed project be discharged?

No effluents

m. Would the proposed project be permitted to discharge effluents into an existing body of water?

☒ No ☐ Yes (describe water use and effluent impact)

n. Would a new or modified National Pollutant Discharge Elimination System (NPDES) permit be required?

☒ No ☐ Yes (describe)

o. Would the proposed project increase or decrease the surface area of an existing body of water?

☒ No ☐ Yes (describe)

p. Would the proposed project adversely affect the quality or movement of groundwater?

☒ No ☐ Yes (describe)

- a. Describe in detail and provide the total quantity of all nonhazardous wastes that would be generated from the project. Solid wastes are defined in RCRA as any solid, liquid, semi-solid, or contained gaseous material that is discarded, has served its intended purpose, or is a manufacturing or mining by-product (40 CFR 260, Appendix I).

	Quantity
☐ None	
☒ municipal solid waste, i.e., paper, plastic, etc.	(2 ft ³)
☐ coal or coal by-products	()
☐ other -- identify	()
	()

- b. Describe in detail and provide the total quantity of all hazardous wastes (40 CFR 261.3) that would be generated, used, or stored under this project.

☒ None ☐ The following hazardous wastes would be generated, used, or stored:

- c. How and where would solid waste disposal be accomplished?

☐ on-site (identify and describe location)

☒ off-site (identify location and describe facility and treatment)

Houghton County Transfer Station/K&W Landfill, Greenland, MI.

- d. How would wastes for disposal be transported?

Trucked

- e. How many trips would be required for landfill disposal?

☐ None ☒ Number of trips: as needed

- f. What volume of the landfill would the solid waste occupy?

☐ None ☒ Volume: 1-3 cubic feet

- g. What Federal, State, and local waste management authorities would have permit authority for the landfill?

Michigan Department of Environmental Quality

- h. Identify the contact person, address, and telephone number for each authority.

Rob Schmeling 906-228-6561

- i. When were these authorities contacted regarding the proposed project (if necessary)? Include results of discussions.

☒ Not contacted

- j. How would hazardous or toxic products be collected and stored?

No hazardous or toxic products will be generated.

- k. If hazardous/toxic solid wastes are subject to land disposal restrictions, how would collection, treatment, and disposal of the wastes be accomplished?

☐ Not subject to RCRA land disposal restrictions.

☐ Subject to RCRA land disposal restrictions (explain)

No hazardous wastes will be generated.

- l. If hazardous wastes would require off-site disposal, have arrangements been made with a certified TSD (Treatment, Storage, and Disposal) facility?

☒ Not required ☐ Arrangements not yet made ☐ Arrangements made with a certified TSD facility (identify):

- m. How would hazardous waste(s) be transported?

☒ No hazardous wastes would be generated

- n. What treatment/storage/disposal methods would be used for hazardous wastes?

☒ No hazardous wastes would be generated ☐ Unknown ☐ Methods that would be used (describe):

11. Health/Safety Factors

- a. Identify any hazardous or toxic substances that would be used in the proposed project.

☒ None ☐ Hazardous or toxic substances that would be used (identify):

- b. What would be the likely impacts of these substances on human health and the environment?

None.

- c. Would there be any potential for workers to be exposed to toxic/hazardous chemicals or wastes?

☒ No ☐ Yes (describe):

- d. Would there be any potential for exposure to extreme temperatures?

☒ No ☐ Yes (describe):

- e. Would there be any special physical hazards associated with the project?

☒ No ☐ Yes (describe):

- f. Would personal protective equipment or clothing be required?

☐ No ☒ Yes (describe):

Standard lab safety gear, gloves & goggles.

- g. Does a worker safety program exist at the location of the proposed project?

☐ No ☒ Yes (describe):

- h. Would safety training be necessary for any laboratory equipment or processes involved with the project?

☐ No ☒ Yes (describe):

Standard lab safety training.

Describe any increases in ambient noise levels in construction and operational activities.

☒ None ☐ Increase in ambient noise (describe):

j. Would project construction result in the removal of natural barriers that act as noise screens?

☒ No construction planned ☐ No ☐ Yes (describe)

k. Identify the highest expected highest decibel level at the closest point of public access.

Ambient.

l. Identify the highest expected decibel level in the work area.

Ambient.

m. Would hearing protection be required for workers?

☒ No ☐ Yes (describe)

12. Environmental Restoration and/or Waste Management

a. Would the proposed project include CERCLA removals or similar actions under RCRA or other authorities, meeting CERCLA cost/time limits?

☒ No ☐ Yes (describe)

b. Would the proposed project include siting, construction, and operation of temporary pilot-scale waste collection and treatment facilities or pilot-scale waste stabilization and containment facilities?

☒ No ☐ Yes (describe)

c. Would the proposed project involve improvements to environmental monitoring and control systems of an existing structure or building?

☒ No ☐ Yes (describe)

d. Would the proposed project involve siting, construction, operation, and decommissioning of a facility for storing packaged hazardous waste for 90 days or less?

☒ No ☐ Yes (describe)

E. REGULATORY COMPLIANCE

1. For the following laws, describe any new or modified permits, manifests, contracts, etc., that would be required for the proposed project:

1. Resource Conservation and Recovery Act (RCRA)

☒ None ☐ Required (describe)

2. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

☒ None ☐ Required (describe)

c. Toxic Substances Control Act (TSCA):

☒ None ☐ Required (describe)

d. Water Pollution Control Act (WPCA):

☒ None ☐ Required (describe)

e. Clean Air Act (CAA):

☒ None ☐ Required (describe)

f. Endangered Species Act (ESA):

☒ None ☐ Required (describe)

g. Floodplains and Wetlands Regulations:

☒ None ☐ Required (describe)

h. Fish and Wildlife Coordination Act (FWCA):

☒ None ☐ Required (describe)

i. Farmland Protection Policy Act (FPPA):

☒ None ☐ Required (describe)

j. National Historic Preservation Act (NHPA):

☒ None ☐ Required (describe)

k. Coastal Zone Management Act (CZMA):

☒ None ☐ Required (describe)

l. American Indian Religions Freedom Act (AIRFA):

☒ None ☐ Required (describe)

m. Wild and Scenic Rivers Act (WSRA):

☒ None ☐ Required (describe)

n. Identify any other environmental laws and regulations (Federal, state, and local) for which compliance would be necessary for this project, and describe the permits, manifests, and contents that would be required.

There are no other laws or regulations for which compliance would be necessary for this project.

F. DESCRIBE ANY ISSUES THAT WOULD GENERATE PUBLIC CONTROVERSY REGARDING THE PROPOSED PROJECT.

☒ None

G. WOULD THE PROPOSED PROJECT PRODUCE ADDITIONAL DEVELOPMENT, OR ARE OTHER MAJOR DEVELOPMENTS PLANNED OR UNDERWAY, IN THE PROJECT AREA?

☒ No ☐ Yes (describe)

H. SUMMARIZE THE SIGNIFICANT IMPACTS THAT WOULD RESULT FROM THE PROPOSED PROJECT.

☒ None (provide supporting detail) ☐ Significant impacts (describe)

IV. CERTIFICATION BY PROPOSER

I hereby certify that the information provided herein is current, accurate, and complete as of the date shown immediately below

DATE: June / 25 / 1998
month day year

SIGNATURE: Allison M. Hein

TYPED NAME: Allison M. Hein

TITLE: Research Engineer/Scientist I

ORGANIZATION: Michigan Technological University, Institute of Materials Processing

V. REVIEW AND APPROVAL BY DOE

I hereby certify that I have reviewed the information provided in this questionnaire, have determined that all questions have been appropriately answered, and judge the responses to be consistent with the efforts proposed. Based on the information in the questionnaire, I conclude the following (check the appropriate box):

- ☐ The proposed action falls under one or more of the categorical exclusions (CXs) listed in Appendix A or B of Subpart D of the DOE NEPA Implementing Procedures and would not (1) violate applicable ES&H requirements, (2) require siting of waste TSD or recovery facilities, (3) disturb hazardous substances (excluding naturally occurring petroleum and natural gas), thus producing uncontrolled or unpermitted releases, and (4) adversely affect environmentally sensitive resources.

Additionally, the proposed action (1) would not present any extraordinary circumstances such that the action might have a significant impact upon the human environment, (2) is not connected to other actions with potentially significant impacts, and (3) is not related to other actions with cumulatively significant impacts.

Based on the Environmental Questionnaire and these conclusions, Categorical Exclusion of the proposed action would be appropriate.

- ☐ The proposed action does not qualify as a CX as identified in Subpart D of DOE's NEPA Implementing Procedures; therefore, the proposed action may require further documentation in the form of an Environmental Assessment or Environmental Impact Statement.

Project Manager _____

Date _____

**FETC CATEGORICAL EXCLUSION -- APPENDIX A OR B OF SUBPART D
DOE NEPA IMPLEMENTING PROCEDURES; 10 CFR PART 1021**

Action or Project No.
Title:
Performing Organization:

FY:
Performance Period:
Location:

THE PROPOSED ACTION FALLS WITHIN THE FOLLOWING CLASS OF ACTIONS (CHECK ONE OR MORE):

General Administration/Management

- ☐ A1 - Routine business actions
- ☐ A2 - Administrative contract amendments
- ☐ A4 - Interpretations/rulings for existing regulations
- ☐ A5 - Regulatory interpretations without environmental effect
- ☐ A6 - Procedural rulemakings
- ☐ A7 - Transfer of property, use unchanged
- ☐ A8 - Award of technical support/M&O/personal service contracts
- ☐ A9 - Info gathering, analysis, documentation, dissemination & training
- ☐ A10 - Reports on non-DOE legislation
- ☐ A11 - Technical advice and planning assistance
- ☐ A12 - Emergency Preparedness planning
- ☐ A13 - Procedural Orders, Notices, and Guidelines
- ☐ A14 - Approval of technical exchange arrangements
- ☐ A15 - International umbrella agreements for energy R&D

Facility Operations

- ☐ B1.2 - Training exercises and simulation
- ☐ B1.3 - Routine maintenance and custodial services
- ☐ B1.4 - Air conditioning installation for existing equipment
- ☐ B1.5 - Cooling water system improvements in existing structures
- ☐ B1.6 - Installation of runoff/spill control retention tanks & basins
- ☐ B1.7 - Communication system & data processing equipment acquisition, installation, operation, removal
- ☐ B1.8 - Screened water intake/outflow structure mods. within permits
- ☐ B1.11 - Fence installation, no adverse effect on wildlife or water flow
- ☐ B1.12 - Detonation/burning of failed/damaged high explosives or propellants in designated areas, within permits
- ☐ B1.13 - Onsite pathway or short access road construction/acquisition
- ☐ B1.15 - Support building or structure, non-waste storage, constr/oper
- ☐ B1.16 - Removal of asbestos in accordance with regulations
- ☐ B1.17 - Removal of PCB items from aboveground structures
- ☐ B1.18 - Water supply well constr/oper. from existing field, no degradation
- ☐ B1.21 - Noise abatement
- ☐ B1.22 - Building relocation to developed area/demolition/disposal
- ☐ B1.23 - Demolition/disposal of buildings, equipment & structures
- ☐ B1.24 - Transfer, disposition, or acquisition of uncontaminated structures or equipment, environmental quality maintained
- ☐ B1.25 - Transfer, disposition, or acquisition of uncontaminated land for habitat preservation/wildlife management
- ☐ B1.26 - Small (<250,000 GPD) WWT facility constr/oper/decom
- ☐ B1.27 - Disconnection of utilities
- ☐ B1.28 - Placement of unused facilities in environmentally safe condition
- ☐ B1.29 - Small onsite constr/decomposition waste disposal facility constr/oper/decom
- ☐ B1.30 - Transfer/transportation actions, quantities incidental to amounts at receiving site
- ☐ B1.31 - Relocation/operation of machinery or equipment, similar use
- ☐ B1.32 - Traffic flow adjustments, existing roads

Safety and Health

- ☐ B2.1 - Modifications to enhance workplace habitability
- ☐ B2.2 - Installation/improvement of building/equipment instrumentation
- ☐ B2.3 - Installation of equipment for personnel safety and health
- ☐ B2.5 - Facility safety and environmental improvements, replacement or upgrade of facility components, no change in useful life

General Research

- ☐ B3.1 - Site characterization/environmental monitoring
- ☐ B3.3 - Research related to conservation of fish and wildlife
- ☐ B3.4 - Transport packaging tests for radioactive/hazardous material
- ☐ B3.6 - R&D or pilot facility construction/operation/decommissioning
- ☐ B3.7 - New infill exploratory, experimental oil/gas/geothermal well construction/operation
- ☐ B3.8 - Outdoor ecological/environmental research in small area
- ☐ B3.9 - Certain CCT Demonstration activities, emissions unchanged
- ☐ B3.11 - Outdoor tests, experiments on materials and equipment components, no source, special nuclear, or byproduct materials

Conservation, Fossil, and Renewable Energy activities

- ☐ B5.1 - Actions to conserve energy, no indoor air quality degradation
- ☐ B5.2 - Modification to oil/gas/geothermal pumps and piping, no flow changes or air emission effects
- ☐ B5.3 - Modification (not expansion/abandonment) of oil storage access/brine injection/gas/geothermal wells; no site closure
- ☐ B5.4 - Repair/replacement of pipeline sections within maintenance provisions of a Section 404 permit
- ☐ B5.5 - Short crude oil/gas/steam/geothermal pipeline constr/oper within a single industrial complex/existing right-of-way
- ☐ B5.6 - Oil spill cleanup operations

Environmental Restoration/Waste Minimization

- ☐ B6.1 - Cleanup actions: small-scale, short-term (<\$5MM & 5 years)
- ☐ B6.2 - Siting/construction/operation of temporary pilot-scale waste collection/treatment/stabilization/containment facilities
- ☐ B6.3 - Environmental control system improvements in existing structures, recycle/release/disposal within permitted facility
- ☐ B6.4 - Packaged hazardous waste storage facility constr/oper/decom
- ☐ B6.5 - Constr/oper/decom of onsite facility for characterizing/sorting or overpacking previously packaged waste (not high-level or spent nuclear fuel; no unpacking)
- ☐ B6.6 - Modification of facility for storing, packaging, or repacking waste (not high-level or spent nuclear fuel)
- ☐ B6.8 - Minor operational changes to minimize waste or reuse materials
- ☐ B6.9 - Small-scale, temporary measures to reduce contaminated GW migration
- ☐ B6.10 - Upgraded waste storage facility (<50,000 ft³) for existing waste constr/oper/decom

Other

- ☐ Specify category:

This Action would not (1) violate applicable ES&H requirements, (2) require siting or waste TSD or recovery facilities, (3) disturb hazardous substances (excluding naturally occurring petroleum and natural gas), thus producing uncontrolled or unpermitted releases, and (4) adversely affect environmentally sensitive resources. Furthermore, this Action (1) would not present any extraordinary circumstances such that the action might have a significant impact upon the human environment, (2) is not connected to other actions with potentially significant impacts, and (3) is not related to other actions with cumulatively significant impacts. Therefore, the proposed Action may be categorically excluded from further review.

Initiator:

Date:

NEPA Compliance Officer:

Date: