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Phase II Interim Report
Regarding Development of Green Chemistry Curriculum

June 29, 2009

Prepared by: Beyond Benign on behalf of Presstek, Inc.

In the Matter of Presstek, Inc.
EPA Docket Nos. CAA-01-2008-0008 and CERCLA-01-2008-0009

EXECUTIVE SUMMARY

I. INTRODUCTION

Green Chemistry is the science of developing safe materials and processes by considering environmental impacts at the earliest stages of innovation and invention. It aims to design out hazards associated with chemicals and intentionally prevent waste rather than cleaning it up after-the-fact. Through the principles of Green Chemistry, scientists focus on pollution prevention and sustainability at the molecular level.

Green Chemistry has rapidly grown over the two decades since its conception. In order to create a workforce and public that are able to actively support this growing field, the education of future scientists is essential. Green Chemistry presents a perfect platform for discussing the opportunities and benefits of careers in chemistry to our society, while stressing the importance of environmental responsibility. This message is one that resonates with young people.

II. PROGRAM DESCRIPTION AND RESULTS

This report summarizes work done as part of phase two of the 2008 Summer Green Chemistry Program. Phase one, completed during the summer of 2008, involved the development of a green chemistry summer program at Quincy High School. Phase two includes the refinement of curriculum created during phase one, along with the development of a Green Chemistry Guide to be used as part of a one-day teacher workshop and to be disseminated to high school and middle school teachers. Between September 2008 and June 2009, Beyond Benign conducted the second phase of the development of a green chemistry guide in collaboration with Quincy High School and a number of local schools. The objectives of this phase included:

- Generate excitement for science
- Learn about green chemistry and sustainability
- Instill environmental stewardship and social responsibility as scientists, consumers and inhabitants of the earth
- Pilot and test developed lessons from phase one
- Determine successes and drawbacks of each lesson during the pilots
- Collect evaluation forms from teachers after each pilot
- Re-write lessons to reflect new changes made from the results of the pilots
- Implement lessons into the Quincy High School science curriculum
- Select lessons for final Green Chemistry Guide
- Plan for phase III of the project (one-day teacher workshop)

The lessons developed from phase one of the project were piloted at Quincy High School, along with several K-12 schools in the Massachusetts and New Hampshire area. As a result of the pilot sessions, BB staff members were able to determine which lessons needed modifications to optimize experimental results, use less material and prevent more waste. All changes were noted in a log that was used to track the work performed during this phase.

The materials from phase one were originally designed so that any high school science teacher could use them to run a summer or semester "Green Chemistry Program" at their location. However during phase two, it was determined that offering the lessons that showcased cutting edge green chemistry technologies in a lesson format would be the most effective way to inspire K-12 students to become scientists and would also allow for easy adoption of the lessons by a school teacher. Additionally, further labwork was also performed in-house by staff members to optimize experiments in the lesson. Based on the results of these experiments, some lessons were omitted from the final guide as they required extensive work beyond the time restraints of this program in order to be optimized.

The participants included staff members from Beyond Benign and teachers and staff from local K-12 schools and colleges. During each pilot session, the lesson was presented by either BB staff, the teacher and/or staff member at the school, or both BB and the teacher/staff. A short introduction to green chemistry was presented to the students before the lesson begins (by the teacher/staff member prior to the pilot visit or by the BB staff member during the pilot visit). The lesson was then conducted, with students doing the lab work as they would any other lab exercise in their science class. Students read the background section, perform the lab procedure, collect and analyze their results and reflect on the green chemistry elements within their lesson. The goal was to show students exciting green chemistry technologies that they are able to mimic in their schools and in order to de-mystify the science, and hopefully to inspire some students to become scientists.

Based on the feedback from teachers in the evaluation forms, Beyond Benign staff members were able to make a more informed decision on how lessons can be further modified to be used in their classrooms. Staff members were also able to determine which lesson plans created the most excitement from the K-12 students, which impacted the decision on which lessons to include in the final Green Chemistry Guide. During the pilots, it was also determined that some lessons would not be included in the final guide as they required more experimental work in the lab before they could be released to a larger audience (i.e., the biodiesel experiment requires extensive testing in the laboratory).

The specific lessons that were implemented into the science curriculum by Quincy High School teachers were tracked closely. As Quincy is a partner school in this project, it was of interest to discover how the use of toxic materials was reduced by the replacement of old lesson plans with the lessons piloted during this phase. It was determined that many of the lessons implemented into their science curriculum successfully replaced lessons that used hazardous materials, although it was difficult to quantify the reduction. Some teacher and student participants of the phase I summer program from Quincy High School also performed outreach at their local middle school, showcasing one of the green chemistry lessons that was optimized during this phase. They also distributed some material developed during phase one, including the coloring books. Their goal was to increase awareness of Green Chemistry in K-12 education through outreach.

Additional feedback from teachers showed that although there was significant interest from teachers, it would be difficult to successfully implement the lessons on a long-term basis due to lack of access to some materials required for the lesson plans. This feedback was taken into consideration while planning for phase three of this project.

During phase two, a key goal was to determine if the concepts presented in the lesson plans could be linked to science standards from the Massachusetts Department of Education Science and Technology/Engineering frameworks. Beyond Benign curriculum developers worked with pilot teachers to review how the lessons fit into their curriculum and matched up the lessons with the appropriate standards. Each lesson plan was included for the strong connections to the Science Inquiry Standards. Several Chemistry content standards were covered as well.

III. PREPARATION FOR PHASE THREE

Phase three of the Green Chemistry Program involves a one-day teacher workshop open to Massachusetts and Regional schoolteachers. The planning of phase three began in March of 2009. Beyond Benign staff, in consultation with Quincy High School teachers, determined the date of the workshop (June 26, 2009) and formed an agenda for the day (included in the supplemental information). The one-day workshop will feature lesson plans developed as a result of phases one and two of the Green Chemistry Program. The lesson plans will be compiled into a Green Chemistry Guide, which will be distributed to participant teachers and made available for download (free-of-charge) on-line. Beyond Benign staff submitted a professional development provider application to the Massachusetts Department of Elementary and Secondary Education and was accepted to award professional development points (PDPs) for the workshop. Massachusetts teachers who attend the workshop will be asked to teach at least one of the lessons from the guide and follow-up with a feedback survey in the fall to receive 10 PDPs.

IV. LESSONS PRESENTED IN FINAL GREEN CHEMISTRY GUIDE

Below is a list of which lessons were chosen to be included in the final green chemistry guide:

- Introduction to Green Chemistry
- Synonyms Simplify
- Recipe Rescue
- How Green Is My Orange (previously the extraction of d-limonene from orange peel using supercritical CO_2)
- VBT/Bio-inspired Polymer
- Blackberry Solar Cell
- Recycling Polylactic Acid

These lessons were chosen as they provide teachers a good starting point for understanding green chemistry concepts so that the teachers can successfully teach green chemistry in their science curricula. These lessons were also the strongest lessons as far as showcasing green chemistry technologies within a lesson plan format, and they were re-written to be appropriate for the high school level. Each lesson plan was also included for the strong connections to the Science Inquiry Standards.

The guide provides an introduction to the 12 principles of Green Chemistry and each lesson plan asks the students to reflect upon the 12 principles and areas of improvement. The lessons challenge the students to evaluate cutting edge technology and formulate their own ideas of how to improve the experiments. The guide is a living document and one of the goals of the training is to broaden the teacher audience and student exposure to the lessons. Teachers will be asked for their feedback and improvements will be made to the lessons.

V. SUPPLEMENTAL INFORMATION

In addition to the program description and overview provided above, the following attachments are included in this report:

A. A list of schools where the lessons were piloted
B. A log of what changes were made after each pilot
C. Evaluation forms from the participants
D. Supplemental Materials:
    i. Write-ups from the Quincy High School teachers which discusses how they implemented some lessons into their curriculum and the impact it had on their school

E. Phase III Preparation Materials:
   i. Workshop Flyer
   ii. Preliminary Registration list

Locations Where Lessons Were Piloted

- Atkinson Elementary School (North Andover, MA)
    - Blackberry Solar Cell
- Bishop Guertin High School (Nashua, NH)
    - Blackberry Solar Cell
    - Recycling Polylactic Acid
- Chester College of New England (Chester, NH)
    - Recycling Polylactic Acid
    - VBT/Bio-inspired Polymer
- Esperanza Academy (Lawrence, MA)
    - Blackberry Solar Cell
- Lowell Catholic High School (Lowell, MA)
    - Blackberry Solar Cell
    - Defining Sustainability
    - Product Life Cycle Analysis
- Maimonides High School (Brookline, MA)
    - Biodiesel: Synthesis and Analysis
    - Blackberry Solar Cell
- Milford High School (Milford, NH)
    - Blackberry Solar Cell
    - VBT/Bio-inspired Polymer
- Newburyport High School (Newburyport, MA)
    - Recycling Polylactic Acid
- Parker Middle School (Reading, MA)
    - Blackberry Solar Cell
- Quincy High School (Quincy, MA)
    - Biodiesel: Synthesis and Analysis
    - Blackberry Solar Cell
    - Categorizing Your Trash
    - Composting
    - Crayon Manufacturing
    - Defining Sustainability
    - Ecological Footprint
    - Extraction of Essential Oils from Fruit Using Steam Distillation
    - Extraction of d-Limonene from Orange Peel Using Supercritical CO_2
    - Intro to Green Chemistry powerpoint
    - Purification and Analysis of Water
    - Re-wording the 12 principles of green chemistry
    - Rooftop Garden

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Quincy Project Phase II Pilot Log

1. **Bishop Guertin High School**
    a. Date & time: Friday, Sept 19, 2008
    b. Location: 194 Lund Road, Nashua, NH
    c. Number of attendees: 62 x 11^{th} and 12^{th} graders (mostly 11^{th} graders)
    d. Brief description:
       Polylactic acid (PLA) lesson piloted 4 times with high school students.
    e. Notes and changes made:
        i. Add these to the materials list: pH indicator or litmus paper, thermometer,
        ii. Small dropper bottles are good to house the 6 M HCl solution – safer and easier for use within classroom setting.
        iii. Teachers can prepare solutions ahead of time (i.e., base solutions - combine water and ethanol to create a 50% ethanol in water mix, add the NaOH)
        iv. Add a warning note on being careful to not allow the solution to boil vigorously. To prevent this, remove the watch glass and/or turn down the heat.

2. **Chester College of New England**
    a. Date & time: Tuesday, Nov 18, 2008; lab session 2:30pm – 5:20pm
    b. Location: 34 Chester Road, Chester, NH
    c. Number of attendees: mostly sophomores, 6
    d. Brief description: PLA and VBT lesson piloted with college students. RD attended.
    f. Changes made:
        i. Add these to the materials list: large filter paper (>90 cm, maybe 150 cm filter paper), empty spray bottle
        ii. Specify that 12 M HCl is the starting HCl concentration. We then dilute that to 6 M HCL, and that is used to converting the hydrolyzed lactate into the acidified lactate.
        iii. Can add in a section for students to figure out how many moles of acid was needed in order to obtain the acidified lactate
        iv. Add a note about how using a hot plate/stir plate combo makes the dissolution of the PLA a LOT faster.
        v. Write an alternate procedure if a hot plate/stir plate combo is not available (put into the teacher sheet section of the lesson plan).
        vi. Each 9 oz. World Centric cup weighs 6 grams. 5 grams of the cup is needed for each setup.

vii. The green ink on the World Centric cups does not dissolve in the process of obtaining dehydrolyzed lactate. Filtering is necessary. Or instruct the students to cut around the green dye, and set the green parts aside.

viii. Add a note on the safeness of using the cleaner on a surface (i.e. lab bench), then rubbing hands on the surface (students at Chester College mentioned "wow, it doesn't leave behind a residue!")

ix. Some notes about the VBT:

1. Using 1-2 coatings of the copolymer on the plastic gives good results. 3+ coatings is too thick and a lot of clumping occurs.
2. The darker the dye (blue or green), the better the result.
3. Experiment with how many grams of dye and mLs of water needed to achieve optimal dye
   - Optimal concentration is 0.1% w/v using FD&C Blue #2 dye in water
4. Use short wavelength on the UV lamp
5. Include structures, and the reaction to make the copolymer in the background teacher section
6. Explain the role of thymine in DNA, and its natural tendency to form thymine dimers under UV light – an example of biomimicry

3. Lowell Catholic High School

a. Date & time: Wednesday, December 10, 2008

b. Location: 530 Stevens Street, Lowell, MA

c. Number of attendees: 20 students (11^{th} and 12^{th} grades)

d. Brief description: Defining sustainability activity. Done with environmental science class.

e. Changes made:

i. We had 45 minutes in class. This exercise took us about 20 minutes to do. Should think of another activity we can do with this lesson plan to take up the entire class period.

ii. Students usually think of sustainability in terms of the environment (it's always the largest column of the three – environment, economic, social equity)

iii. One idea is to have split the class into groups to compete for points.

1. Team gets a point for every time their idea is listed (can be more than once if their idea is under more than one category)
2. Make sure that items that can be categorized in more than one column is done

iv. Remember not to label the headers (what the 3 Es are) until after the list is complete

v. Timing of things:

1. Having the students label the columns will take about 5 min
2. Going around and getting the students' input for what they want to see last beyond their lifetime takes about 15 minutes

3. Passing out the different definitions of sustainability and discussing them takes about 5-10 minutes
4. Discussing in detail what economics, environment and social equity (especially the social equity part) can take 5 minutes
5. Determining winner takes about 5 minutes

4. Lowell Catholic High School

a. Date & time: Wednesday, December 10, 2008
b. Location: 530 Stevens Street, Lowell, MA
c. Number of attendees: 120 students (10th and 11th grades)
d. Brief description: Product life cycle analysis project. All CP (college prep) chemistry level students will spend 2 quarters (a semester) on this research project from Jan – Mar 2009.
e. Changes made:
   i. Added more info to teacher sheet
      1. Linear vs. cyclical life cycle (diagrams added too)
      2. How design for disassembly ties into sustainability (gave brief info on Europe's take back legislation, and mentioned the REACH program)
      3. Gave tips on student presentation formats (electronic vs poster)
      4. Recommended some products that were research before, added their prices as paid for from Wal-Mart
   ii. Revised student worksheet
      1. Re-organized how the questions were grouped
      2. Added more questions
      3. Added background, objectives, goals, assignment sections
      4. Added recommendation to view "The Story of Stuff with Annie Leonard" and consider how the 12 principles of green chemistry relate to their product, and how were the 3 criteria for a green chemistry technology related (cost, performance, safety)?
   iii. Re-worked assessment section

5. Maimonides High School

a. Date & time: Tuesday, December 16, 2008
b. Location: 34 Philbrick Road, Brookline, MA
c. Number of attendees: 18 students (11th and 12th grades)
d. Brief description: Synthesis of biodiesel (lesson 2, part 1).
e. Changes made:
   i. Send the background information to teachers to distribute to students ahead of time
   ii. Specify what volumes of each chemical are needed in the materials section
   iii. Experiment with doubling the volumes of chemicals (40 mL EtOH, 0.7 g NaOH, 40 mL veggie oil)

iv. State that using a hot plate/stir plate combo makes this experiment go a lot easier

v. NaOH pellets take longer to dissolve. Look into using finely grounded NaOH or NaOH solution (in EtOH).

   1. If using NaOH in solution, calculate # of NaOH moles needed (the answer is 0.00875 moles of NaOH). NaOH FW = 40 g/mol. 0.35 grams is what the synthesis originally calls for. 0.35 g x 1 mol/40g = 0.00875 moles. Depending on the amount of solution that the teacher wants to prepare, and on what concentration they want to prepare, the calculation here will vary from teacher to teacher. Remember molarity (M) is moles/liter.
   2. Experiment if making 100 mL of a 1.0 M NaoH solution is sufficient for a class of 30 students (15 setups if the students work in pairs)
      a. The answer is no.
         i. Each group would need 8.75 mL 1.0 M NaOH
         ii. 15 groups would need 131.25 mL (8.75 x 15 = 131.25)
         iii. 30 groups would need 262.50 mL (8.75 x 30 = 262.50)
      b. The teacher could have the students working in groups of 3
         i. 10 groups would need 87.50 mL (8.75 x 10 = 87.5)
      c. The teacher could prepare the 1.0 M NaOH solution twice
   3. Dissolving 4 grams NaOH pellets in 100 mL ethanol gives 1.0 M NaOH. Note: the solution turns yellow over time. Do not be alarmed.

vi. Provide the basic calculation for preparing 0.1 M acetic acid from concentrated stock solution

   1. C1V1 = C2V2.
   2. C1 = 17.4 M, V1 = x mL, C2 = 0.1 M, V2 = 100 mL. → [(0.1 M)(100 mL)]/(17.4 M) = x mL → x mL = 0.575 mL → 0.575 mL x 1000 uL/1 mL = 575 uL.
   3. If we want to make 100 mL of 0.1 M acetic acid from 17.4 M acetic acid (concentrated acetic acid), we would add 575 uL of the concentrated acetic acid into a 100 mL volumetric flask, and QS to the 100 mL line with DI water.

vii. Add weigh boats/paper, spatula/scoopula, parafilm, scissors to the list of materials in lesson 2, part 1 (synthesizing biodiesel)

viii. In lesson 2, part 1 – add to the procedure to cover the test tubes with parafilm before allowing the biodiesel to settle and separate.

ix. In lesson 2, part 1 – add to the procedure to label the test tubes with the scientists' initials, date, and "biodiesel mix"

x. It took the students at Maimonides HS 60 minutes to do lesson 2, part 1

xi. Specify in the teacher sheet to announce to the students "DO NOT MIX YOUR SOLUTION WITH THE THERMOMETER OR USE YOUR THERMOMETER TO CRUSH THE NaOH!". Also add that note in the student sheet.

xii. Make pre-lab questions before the experiment is to be performed.

xiii. For the 20 mL EtOH, 20 mL veggie oil, 0.35 g NaOH, pouring the biodiesel mix into one 25 x 150 mm test tube is the perfect size (the capacity of these 25 x 150 mm test tubes is ~50 mL).

xiv. Write alternate procedures in the teacher sheet if a hot plate/stir plate combo is not available (this is the 2nd pilot visit I've had that's been complicated because the school does not have a hot plate/stir plate combo).

xv. Had interns collect data for biodiesel lesson

1. Densities of different oils

Oil	Density (g/mL)
Basil	0.9613
Canola	0.9346
Corn	0.9054
Flax	0.8990
Peanut	0.8932
Safflower	0.8660
Sesame	0.8775
Soybean	0.9550
Vegetable	0.9200
Walnut	0.9225

2. Which oils make the best biodiesel
    a. Vegetable, Corn and Walnut oils make good biodiesel
    b. Basil oil makes bad biodiesel

xvi. Buy more different types of oils

xvii. Added answers to questions for teacher sheet

6. Maimonides High School

a. Date & time: Thursday, December 18, 2008

b. Location: 34 Philbrick Road, Brookline, MA

c. Number of attendees: 18 students (11th and 12th grades)

d. Brief description: This was a 45 minute session. Separation of biodiesel and analysis of biodiesel (lesson 2, part 2 and lesson 3, part 1)

f. Changes made:

i. A dry ice water bath does not get the temperature low enough for freezing the biodiesel.

ii. Instead, add the tube directly in a tub of dry ice pellets. Ensure uniform contact of glass test tube to the dry ice. Recommended to crush the dry ice in a mortar and pestle. Wear appropriate gloves for handling of dry ice.

7. **Quincy High School**
    a. Date & time: January 2009
    b. Location: Quincy, MA
    c. Number of attendees: 22 x 9-12th graders
    d. Brief description: Julie Krieger ran the defining sustainability and compost lesson plan.
    f. Changes made:
        i. Would like to see more graphical images
        ii. Stress vocabulary in the lessons (new vocabulary words could be bolded and defined)
        iii. Add more background info on different types of waste disposal
        iv. Add more info on chemical pesticides

8. **Milford High School**
    a. Date & time: Wednesday, April 8, 2009
    b. Location: Milford, NH
    c. Number of attendees: ~100 x 11th graders
    d. Brief description: Blackberry solar cell and VBT activities
    e. Changes made:
        i. Blackberry solar cells – no changes made. They loved it as it.
        ii. VBT – the students had a hard time understanding its connection to real-world applications. Need to rewrite the lesson to reflect the connection clearly.
        iii. Explain more what photoresists are, and where they are used

9. **Newburyport High School**
    a. Date & time: Friday, May 15, 2009
    b. Location: Newburyport, MA
    c. Number of attendees: 40 students (11th and 12th grades)
    d. Brief description: Polylactic acid (PLA) activity
    f. Changes made:
        i. Shoot for a pH of 4-5 for acidified lactate.
        ii. Can we try another base (that will hydrolyze the PLA polymer, but won't be a strong base with a pH of 14 like NaOH?)
        iii. Can we try a weaker acid to neutralize the solution? Maybe acetic acid?
        iv. Can we try enzyme hydrolysis? β-glucuronidase is a good enzyme for this purpose, but it's costly (therefore we won't be meeting green chemistry criteria of cost, performance and safety).
        v. In-process monitoring of pH change with blue litmus paper to prevent pollution (if pH strips were used at every 50 drop interval)
        vi. About 400-450 drops of 6 M HCl were needed to drop pH from 14 to 4-5.

10. Esperanza Academy

a. Date & time: Monday, May 18, 2009
b. Location: Lawrence, MA
c. Number of attendees: ~20 x 5th graders
d. Brief description: Blackberry solar cell activity
e. Changes made:
   i. They only had good things to say. They really like how the material was presented in the allotted time slot. No changes made.

11. Atkinson Elementary School

a. Date & time: Wednesday, May 27, 2009
b. Location: North Andover, MA
c. Number of attendees: ~60 x 5th graders
d. Brief description: Blackberry solar cell activity
e. Changes made:
   i. Sue (teacher) would love to do this lesson with her students, but she would need access to some of the materials, like the ITO coated glass slides and the TiO2 coating. Make note of this for phase three.

12. Parker Middle School

a. Date & time: Friday, June 12, 2009
b. Location: Reading, MA
c. Number of attendees: ~100 x 8th graders
d. Brief description: Blackberry solar cell activity
e. Changes made:
   i. Allow the students to interact more
   ii. The lesson plan was written for a high school level, which this 8th group did have some difficulty with
   iii. Would like to have some of these materials available (glass slides and TiO2 coating)
   iv. Would need a large amount of slides for all the ~100 students

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Lesson Plan Evaluation Form

1. Date Beyond Benign visited your classroom: 9/19/2008
2. Name of presenter(s): Raks Derival
3. Lesson plan performed: Recycling polylactic acid into a cleaning solution
4. Teacher name: Dot Clare
5. School name: Bishop Guertin High School
6. Class name: Environmental Science
   (chemistry, biology, environmental science, etc.)
7. Grade level(s): 12-Nov
8. Total # of students: 68

Please place an X next to the box that best desribes the lesson.

9. The information in the lesson was thorough and complete
   [x] Agree [ ] Neutral [ ] Disagree
10. It is clear how green chemistry principles are applicable in the lesson
    [x] Agree [ ] Neutral [ ] Disagree
11. The lesson showed how green chemistry provides a solution to an environmental/health problem
    [x] Agree [ ] Neutral [ ] Disagree
12. Using the lesson plan in your curriculum will reduce the use of hazardous materials
    [x] Agree [ ] Neutral [ ] Disagree
13. The lesson was inquiry-based (allowed students to do the thinking instead of teaching at them)
    [x] Agree [ ] Neutral [ ] Disagree
14. The lesson connects to the curriculum
    [x] Agree [ ] Neutral [ ] Disagree
15. You would use this lesson as part of your teaching curriculum
    [x] Agree [ ] Neutral [ ] Disagree
16. How did you reduce or eliminate the use of hazardous materials by using this lesson? (if applicable)

    Utilize materials that can be recycled

Please fill out the next page