



## Team Advisors

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## Mission Folder: View Mission for 'Styro-Filter'

<b>State</b>	Ohio
<b>Grade</b>	8th
<b>Mission Challenge</b>	Environment
<b>Method</b>	Engineering Design Process
<b>Students</b>	Lemonhead AlmondJoy Jujube NestleCrunch

### Team Collaboration

**(1) Describe the plan your team used to complete your Mission Folder. Be sure to explain the role of each team member and how you shared and assigned responsibilities. Describe your team's process to ensure that assignments were completed on time and deadlines were met.**

Our team has 4 members: Jujube, Lemonhead, AlmondJoy, and NestleCrunch. We have been meeting about 4 hours a week since August 2015 in order to make sure that we had enough time to design, test and analyze our idea. In order to complete our Mission Folder, we divided the work evenly, but we did have specific areas of focus based on our strengths:

1. Jujube led our testing when we tested Styro-Filter on dirty water. She also led the development and construction of our prototype filter with our activated carbon derived from Styrofoam.
2. Lemonhead led the communication with experts. He set up meetings with them to discuss our project, and worked with Battelle for various aspects of testing and analysis.
3. NestleCrunch led our research in books, journal articles, and websites. She also coordinated all of our findings in Google Docs and was the main editor of the Mission Folder.
4. AlmondJoy led our experiments by melting down polystyrene and carbonizing it many times. He also led experiments to activate our carbon samples in our attempt to achieve high surface area.

To make sure that the project tasks were completed on time, we posted each team member's assignments and deadlines on a shared Google Doc. We always made sure to encourage each other to stay focused and on track. We also used Google Docs to record our research and to work on the Mission Folder outside of meetings. This way, if team members could not make it to a meeting, they could still work on the project from home and see the team's progress (see attached Task Schedule). After working together to create and test our solution, we divided up the questions to complete each part of the Mission Folder.

#### Uploaded Files:

- [\[ View \]](#) **Task Schedule** (By: Advisor, 02/29/2016, .pdf)

*Weekly team schedule for completing the Mission Folder*

### Engineering Design

#### Problem Statement

**(1) What problem in your community did your team try to solve? Why is this problem important to your community?**

The problem in our community that we tried to solve was the overwhelming amount of Styrofoam, or expanded polystyrene, that is discarded as trash. We found that every year in the US alone, 1.9 billion pounds of Styrofoam is thrown away, filling up a staggering 30% of landfills (Figure 1). This problem is also prevalent throughout the world, as it accumulates in the oceans and beaches (Figure 2). Much of the Styrofoam waste (1.7 billion pounds) is from packaging, plates, and over 25 billion Styrofoam cups. It costs a staggering \$42 million annually to add all of this waste to landfills in the US. Furthermore, Styrofoam takes thousands of years to degrade. It is discarded in such high quantities because it is cheaper to produce new polystyrene than it is to collect, transport, and process material for recycling. Styrofoam is also very difficult to recycle because of its toxicity. The fumes released when Styrofoam is re-processed are hazardous, and few places will accept Styrofoam without discarding it directly into landfills.

This problem is important to our community because there are no Styrofoam recycling facilities in our state. When we toured our local recycling facility, we were surprised that this recycling company, along with most facilities throughout the country, took no effort to do anything with the Styrofoam except send it on to the landfill. This means that our community does not even attempt to recycle Styrofoam, resulting in more and more landfill volume being consumed. So we asked ourselves, "Is it possible to transform an environmental PROBLEM into an environmental SOLUTION?" And the answer was YES!

**(2) List at least 10 resources you used to complete your research (e.g., websites, professional journals, periodicals, subject matter experts).**

## Experts:

Cannon, Fred. Professor, Department of Civil Engineering, Penn State University. Personal interview. 17 Sept. 2015.

Clay, John. Professor, Department of Chemical Engineering, Ohio State University. Personal interview. 20 Aug. 2015.

Kissell, Jonathan. Senior Communication Coordinator, Rumpke Waste & Recycling. Personal interview. 11 Aug. 2015.

Knappe, Detlef. Professor, Dept. of Civil Engineering, North Carolina State University. Personal interview. 17 Sep. 2015.

Roy, Alan. Technical Account Representative, Calgon Carbon Corporation. Personal interview. 8 Oct. 2015.

## Journal articles:

Birbas, Daniella. Preparation of Activated Carbon: Forest Residues Activated with Phosphoric Acid and Zinc Sulfate. Thesis. Royal Institute of Technology of Stockholm Sweden, 2011.

Tan, I. A., A. L. Ahmad, and B. H. Hameed. "Preparation of activated carbon from coconut husk." Journal of Hazardous Materials, 2008.

Toles, Christopher, Sue Rimmer, and James Hower. "Production of Activated Carbons from a Washington Lignite Using Phosphoric Acid Activation." Carbon, 1996.

Volperts, Aleksandrs. "Synthesis and Application of Nanoporous Activated Carbon in Supercapacitors." Material Science and Applied Chemistry 2015.

Yakout, S.M. "Characterization of Activated Carbon Prepared by Phosphoric Acid." Arabian Journal of Chemistry, 2012.

## Websites:

"Activated Carbon." NobleClays Innovations. n.d. Web. 9 Oct. 2015. <http://www.nobleclays.com/innovations.html>.

"Brunauer, Emmett and Teller (BET) Theory." Particle Analytical, n.d. Web. 15 Sept. 2015. <http://particle.dk/methods-analytical-laboratory/surface-area-bet/surface-area-bet-theory/>.

Engber, Daniel. "How Does Activated Carbon Work?" n.d. Web. 21 Sept. 2015. [http://www.slate.com/articles/news\\_and\\_politics/explainer/2005/11/how\\_does\\_activated\\_carbon\\_work.html](http://www.slate.com/articles/news_and_politics/explainer/2005/11/how_does_activated_carbon_work.html).

Kiger, Patrick J. "10 Innovations in Water Purification." HowStuffWorks. HowStuffWorks.com, n.d. Web. 12 Sept. 2015. <http://science.howstuffworks.com/environmental/green-tech/sustainable/10-innovations-water-purification.htm>.

## Reference books:

Connett, Paul. The Zero Waste Solution: Untrashing the Planet One Community at a Time. White River Junction: Chelsea Green Publishing, 2013.

Feed, Eric Corey, and Kevin Daum. Green \$ense for the home : Rating the Real Payoff from 50 Green Home Projects. Newton: Taunton Press, 2010.

Mulder, Michelle. Trash Talk: Moving Toward a Zero-Waste World. Victoria: Orca Book Publishers, 2015.

Szaky, Tom. Make Garbage Great : The TerraCycle Family Guide to a Zero-Waste Lifestyle. New York: HarperCollins Publishers, 2015.

Szaky, Tom. Outsmart waste : The Modern Idea of Garbage and How to Think Our Way Out of It. San Francisco: Berrett-Koehler Publishers, Inc., 2014.

Wilcox, Charlotte. Recycling. Minneapolis: Lerner Publications, 2008.

**(3) Describe what you learned in your research.**

Through journal articles, reference books, internet searches, and interviews with experts, we found interesting and intriguing information about Styrofoam: both how it is made and how it is used. Because Styrofoam waste is a major problem in the US - almost 2 billion pounds are thrown away every year and responsible for almost 30% of space in landfills - we decided to research existing solutions for reusing or recycling Styrofoam.

We found several existing solutions. However, none of them were viable or cost effective. One solution is called Styrocrete, which is made by mixing new Styrofoam beads with cement to make a lightweight concrete (Figure 3). The value and use of Styrocrete is unfortunately quite limited because it has low compressive strength and a tendency to crack and break. Therefore, the opportunity to regrind and use waste Styrofoam in concrete is generally limited to non-structural decorative applications.

Another existing solution is the reprocessing or reuse of polystyrene (Figure 3). This procedure can turn the used Styrofoam back into polystyrene pellets. However, the collection and processing for recycling Styrofoam is very expensive and there are no means of automated separation. Moreover, the value of re-processed polystyrene is low because of the danger of contaminants which cannot be avoided. In general, manufacturers prefer to use virgin or new polystyrene because of its extremely low cost (less than \$1/kg).

Recently, researchers have discovered a mealworm that eats polystyrene (Figure 3). While the concept is very exciting, this process is extremely slow, with each worm eating only about 3.6mg of Styrofoam per day. Given the time and number of worms needed, this idea appears to be too inefficient to tackle the nearly 2 billion pounds of Styrofoam that accumulate each year in US landfills.

Discovering that these existing solutions will likely not resolve the problem of Styrofoam waste, we further investigated the chemical makeup of polystyrene. We learned that polystyrene, or C<sub>8</sub>H<sub>8</sub>, is a synthetic polymer composed of long chains of styrene and consists of more than 92% carbon (Figure 4). With such a high percentage of carbon, we started thinking that we might be able to utilize the carbon in a useful way. We eventually hypothesized that with heat and compression, we could possibly turn polystyrene into pure carbon.

Common products made of pure carbon include graphite (e.g., pencil lead), diamonds, and activated carbon (major component in most water filters). While the creation of

graphite and diamond seemed a little out of reach, we thought we might be able to develop a process to convert Styrofoam into activated carbon. We learned that activated carbon can clean water or air through the filtration process of adsorption. When carbon is activated, it forms tiny micropores and small pockets that increase its surface area (Figures 5 and 6). In fact, one teaspoon of activated carbon can have a surface area that is equivalent to a football field! As water flows through, the tiny micropores catch and trap pollutants and contaminants. One drawback with activated carbon is that it can only be used until its pores have filled up, which is why the filter must be frequently replaced. An ongoing need therefore exists for new activated carbon to keep water filters working properly.

We reached out to several professors and experts about activated carbon, and we learned that activated carbon is usually made from wood or coal using a very high temperature process. Every expert we talked to told us that they had never heard of anyone making activated carbon from Styrofoam, but that it could possibly work due to its unique chemical structure.

#### Experimental Design

**(4) Develop a design statement. Be sure to describe what exactly your device should be able to do. Do not describe HOW it's going to do what it needs to do.**

Our goal is to design a cost effective process that will efficiently convert expanded polystyrene waste into activated carbon for water filtration. Our process will re-claim a waste material and produce an activated carbon material that will effectively filter water to remove contaminants. The process must be feasible and viable for anyone across the globe. We therefore aim to create a system that will reduce the amount of Styrofoam waste entering landfills and also filter dirty water, all through the process of making activated carbon.

**(5) Determine the criteria for a successful solution and identify constraints for your design. Discuss what the device must have in order to accomplish its job and the restrictions of the device (i.e. the size, the cost, the weight, etc.).**

Our process must be designed such that it achieves several goals. First, we need to design a process which can convert Styrofoam into activated carbon at high efficiencies. We hope to convert at least 50% of the Styrofoam mass into carbon. Second, a successful process would result in an activated carbon that has a surface area that corresponds to a high amount of microporosity. In other words, we hope to produce a carbon that has a surface area much greater than 1m<sup>2</sup>/g. Higher surface area would indicate the presence of microporosity and the potential to effectively filter out contaminants in water. If microporosity can be demonstrated, then we will attempt to confirm the effectiveness of our activated carbon product in filtering contaminants from water.

**(6) Identify the relevant variables you will use to test your prototype or model and explain how you will measure your variables.**

The most important variable that we will use to test our prototype is the specific surface area (square meters per gram) of our product. Surface area should be a direct reflection of the effectiveness of our activated carbon samples. We will measure the surface area using a BET (Brunauer–Emmett–Teller) analyzer, which uses nitrogen adsorption to measure surface area.

In order to confirm the effectiveness of our activated carbon samples, we will measure the concentration of contaminants in water (parts per million) before and after being filtered with the activated carbon samples. For our control, we will use commercial grade activated carbon (supplied by Calgon Carbon) to compare with our activated carbon product. We will use chemical test strips to measure the reduction in contaminant concentration in the water after we run it through our activated carbon filter.

#### Build Prototype or Model

**(7) Develop a design and list the materials you used in your design. Include technologies you used (e.g., scientific equipment, internet resources, computer programs, multimedia, etc.).**

The materials used in our prototype were the following:

- Styrofoam
- Metal Containers
- Propane Grill
- Laboratory Furnace
- Mallet
- Phosphoric Acid
- Potassium Hydroxide
- Centrum Multivitamins
- Chlorine Bleach
- Calgon Carbon Activated Carbon (grade Filtrasorb® F-200)

To analyze our results, we used the following laboratory instruments:

- BET Surface Area Analyzer - Micromeritics ASAP 2020 (Figure 7)
- Carolina Biological Water Test Kit - Item # 652748 (Figure 8)

**(8) Explain how you built your prototype(s) or model(s). Include each of the steps in your process.**

To build our prototype, we first had to develop a process to densify and carbonize polystyrene. We started out with a large Styrofoam block. Since Styrofoam is over 95% air, we first compressed and densified the expanded polystyrene by heating it at 150°C to form a solid polystyrene mass that was hard and brittle (Figure 9). We then performed a series of experiments to develop a process to carbonize the polystyrene (Figure 10). We wanted to maximize the yield of carbon compared to the initial quantity of Styrofoam. After many hours of testing using different heating conditions, along with MANY failures, we found that the polystyrene could be converted to carbon by heating the Styrofoam at 300°C for 5 hours as our first heat treatment (Figure 11). We learned that it was critical to perform this heat treatment at relatively low temperatures in an enclosed container. These conditions minimized the amount of polystyrene that decomposed to form a gas. Once we formed the carbonized samples, we used a mallet to break the carbon into small sand-sized granules for further processing.

Next, we experimented with different chemical reagents (potassium hydroxide and phosphoric acid) to etch the carbon and create the micropores for the activated carbon product. The best result (as outlined in Figure 12) was obtained by rinsing the carbon in phosphoric acid (H<sub>3</sub>PO<sub>4</sub>) as shown in Figure 13. Finally, we put the chemically treated carbon in a second heat treatment at 400°C for 5 hours. This resulted in activated carbon with a surface area of over 108 m<sup>2</sup>/g, which was measured using a BET surface area analyzer (Figure 14). This surface area is equivalent to the area of a volleyball court, in only 1 gram of activated carbon!

We then set out to prepare a simple prototype filter with our activated carbon samples. We first cut off the top of a PET water bottle, keeping the lid attached. We drilled three holes (approx 1mm diameter) in the lid of the bottle. Next we inserted a coffee filter into the top of water bottle (oriented upside down) to keep the activated carbon contained (Figure 15). We carefully poured the activated carbon samples into the bottle so that it would sit within the coffee filter. Lastly, we added a second coffee filter on top of the activated carbon to filter out any larger particles. We prepared side by side samples using both commercial grade activated carbon (Calgon Carbon Filtrasorb® F-200) and our own activated carbon sample which a surface area of 108 m<sup>2</sup>/g.

Please see a video summary of our process at <https://youtu.be/YbUSn-hBeMA>.

#### Test Prototype or Model

##### **(9) Describe the data you collected and observed in your testing (use of data tables, charts, and/or graphs is encouraged).**

Testing was critical during each stage of development of the Styro-Filter project. We investigated several variables including the initial heating to carbonize the polystyrene, chemical etching, and a second heat treatment to activate the carbon (Figure 14). We performed nine different tests using various combinations of heating and chemical treatments, all with different outcomes. In our first three tests, we heated the densified polystyrene to extremely high temperatures of 800°C, 600°C, and 500°C, all for 2 hours. The results for these three tests were very discouraging - each polystyrene sample completely vaporized.

To prevent the decomposition and vaporization of the polystyrene, we decided to significantly reduce the initial heat treatment temperature. We tried a low temperature of 300°C and found that it carbonized quite well in 5 hours. This result was very encouraging, and it allowed us to start investigating how to best produce high surface areas.

In our subsequent testing (Tests 4-9), we investigated various chemical etchants and heat treating conditions. For our fourth test, we rinsed the Styrofoam with potassium hydroxide (KOH), but the surface area of this treated Styrofoam was less than 1 m<sup>2</sup>/g. For our fifth and sixth tests, we ran the Styrofoam through a second heat treatment. We rinsed both samples with potassium hydroxide, but the fifth test failed. For our sixth test, we heated the Styrofoam at a lower temperature than the fifth test, and heated it for a longer period of time. This test turned out to be successful, but it only produced a surface area of 4 m<sup>2</sup>/g.

We continued to test, looking for a larger surface area. On our last three tests, we rinsed our samples with phosphoric acid (H<sub>3</sub>PO<sub>4</sub>) instead of potassium hydroxide. Our seventh and eighth tests did not achieve measurable surface areas, but when we tested with the second heat treatment for 5 hours at 400°C, we successfully converted the Styrofoam into activated carbon, with a surface area of 108 m<sup>2</sup>/g!

After our very encouraging result, we set out to confirm whether our activated carbon derived from polystyrene could really work in a water filter. To test for chlorine, we added chlorine bleach to a sample of distilled water. To test for iron and copper, we crushed a Centrum multivitamin and added various amounts to a sample of distilled water. We tested various chlorine bleach and vitamin concentrations with Carolina Biological water test strips until we produced water samples at the high end of each contaminant scale: Iron (1 ppm), Copper (1 ppm), Chlorine (5 ppm).

We poured each water sample through two activated carbon filters: (1) a control filter made using Calgon Carbon Filtrasorb® F-200, and (2) our own activated carbon sample with a surface area of 108 m<sup>2</sup>/g. We measured the change in concentration of each water sample by following instructions on the water test strips (Figure 16). While not quite as effective as the control samples, our results showed that the Styro-Filter sample was still very effective in filtering and reducing the concentration of each contaminant (Figure 17).

##### **(10) Analyze the data you collected and observed in your testing. Does your data support or refute your design statement? Do not answer with yes or no. Explain your answer using 'Our data supports/refutes the design statement because...'**

After reviewing all of our data, we concluded that the results clearly support our design statement because we successfully developed a process to convert Styrofoam into activated carbon at high efficiencies. In fact, we measured conversion efficiencies above 75% from the mass of Styrofoam to the mass of carbon. We furthermore produced activated carbon with surface areas greater than 100 m<sup>2</sup>/g, so that it had sufficient microporosity to filter contaminants from water. Our water filtration tests in fact proved that the activated carbon of Styro-Filter removed high levels of contaminants from water (Figure 17).

We are confident that further development of our chemical etching and heat treatments would enable us to match the higher surface area of the commercial grade activated carbon. We would then expect to be able to match the higher filtration efficiencies of the commercial grade product.

##### **(11) Explain any sources of error and how these could have affected your results**

There could have been several sources of error during our experiments and analysis. Two key variables during our experiments were temperature and oxygen content. In each of our heat treatments, temperature was measured using a thermocouple. However, the thermocouples were not actually placed within the samples, but inside the furnace (or grill for many experiments). There were likely differences between the sample temperature and the temperature at the thermocouples. In all of our later experiments which were performed in closed containers, there may also have been some differences in oxygen content from one test to the next. These differences could come from small variations in the containers themselves. These potential variabilities in temperature or oxygen content, however, should only affect our understanding of the process conditions. Our resultant samples are still valid regardless of these potential measurement errors..

Our primary measurement of the product was the BET surface area. Surface area measurements were made on a laboratory instrument at Battelle Labs. It is possible that there were errors in the calibration of this instrument. However, we relied on the generous support of technicians at Battelle to perform these measurements. Since Battelle is certified under various quality standards (ISO 9001:2008, AS9100C, and ISO13485), we believe that the BET instrument was properly calibrated.

Another potential source of error was related to our measurements of water contaminants before and after filtering. We used a water testing kit that relies on a visual method of determining the amount of each contaminant in the sample. Specifically, the method used test strips and reference charts to match the color of the strip with the corresponding measurement on the chart. Sometimes the color of the strip was in between two colors on the reference chart, so we had to estimate the corresponding measurement. To minimize error, we made sure that we worked under a bright light and that all of us agreed on the measurement.

#### Drawing Conclusions

##### **(12) Interpret and evaluate your results and write a conclusion statement that includes the following: Describe what you would do if you wanted to retest or further test your design. Evaluate the usefulness of your prototype or model. What changes would you make to your prototype or model for the future, if any?**

Our results are a positive proof-of-concept that it is possible to convert Styrofoam waste into a useful product, activated carbon. We were also able to demonstrate that our Styrofoam-derived activated carbon sample was effective in reducing the quantities of several chemical contaminants in water.

To further test our design, we would like to conduct more accurate and sophisticated tests to understand the effectiveness of our activated carbon in reducing various pollutants and contaminants in water and air.

We would also like to achieve a greater surface area with our activated carbon. To do this, we would experiment with different chemical concentrations and other chemical reagents to further etch the carbon. We would also vary the temperature and time of the heat treatments. Since we have only tested a few conditions, we hope that more testing could reveal other process conditions that would further increase the amount of surface area in our activated carbon.

Our prototype is very useful because we can take Styrofoam waste and turn it into activated carbon. We took a very challenging environmental problem and transformed it into an environmental solution that can help reduce Styrofoam trash AND filter dirty water with a single innovative approach!

Uploaded Files:

- [\[View\]](#) **Figures** (By: Advisor, 02/29/2016, .pdf)

*Figures for Styro-Filter Mission Folder*

## Community Benefit

**(1) How could your design help solve your problem and benefit your community? Describe next steps for further research/design and how you have or how you could implement your solution in the future.**

Our design could help solve the problem of excessive, non-recyclable Styrofoam waste by turning discarded Styrofoam into activated carbon for water purification. This innovative approach would not only reduce the amount of Styrofoam trash that fills over 25% of landfills in our community, but also create a low cost and effective method of producing activated carbon. Furthermore, our solution has the potential to benefit third world countries, where there are large amounts of Styrofoam trash, but limited ways of purifying water.

One of our future research steps is to optimize our chemical reagents and heat treatments to further increase the surface area of our activated carbon product. We would also like to promote our solution in the community to raise awareness of the growing problem of Styrofoam trash and to present a feasible solution of converting Styrofoam waste into activated carbon. Our design and prototype, at the moment, is just a proof of concept on a laboratory scale. However, we would like to conduct further research and tests to see if this process can be scaled up to handle a large amount of Styrofoam as part of an industrial waste stream.

We talked with a variety of experts in the fields of activated carbon and of Styrofoam waste, and they were all very enthusiastic about Styro-Filter. They were optimistic that Styro-Filter could be easily scaled up and implemented commercially. With this confirmation from university professors and industry researchers in the fields of chemistry, chemical engineering, and the activated carbon industry, we believe that we have developed a very unique and revolutionary innovation to deal with one of the most challenging environmental waste problems today.

## Mission Verification

**(1) Does your Mission Folder project involve vertebrate testing, defined as animals with backbones and spinal columns (which include humans)? If yes, team must complete and attach an IRB approval form.**

No

**(2) Did your team use a survey for any part of your project? If yes, team must complete and attach a survey approval form.**

No

**(3) You will need to include an abstract of 250 words or less. As part of the abstract you will need to describe your project and explain how you used STEM (Science, Technology, Engineering and Mathematics) to improve your community**

Every year in the US alone, 1.9 billion pounds of Styrofoam is thrown away, and it fills up a staggering 30% of landfills. The US disposes over 25 billion Styrofoam cups alone every year. These high statistics usually occur because it is cheaper to produce new polystyrene than it is to collect, transport, and process material for recycling. Through our research, we found that there were no good existing solutions for Styrofoam waste.

Using STEM, we developed an innovative solution to this growing problem. Our solution is called Styro-Filter, in which we successfully convert Styrofoam waste (expanded polystyrene) into activated carbon that can be used to filter water. Because polystyrene is composed of over 92% carbon, we performed a series of experiments to convert polystyrene into carbon. After many failures and over 50 hours of experiments, we were able to successfully convert polystyrene into carbon with over 75% efficiency. We then investigated several chemical reagents including phosphoric acid and potassium hydroxide which, coupled with heating, effectively etched the carbon to achieve a surface area of over 100 m<sup>2</sup>/g!

We then made a prototype water filter using a disposable water bottle filled with the activated carbon we made from Styrofoam. By measuring the reduction of various chemical contaminants, we found that our Styro-Filter was very effective for filtering water. In summary, we took a very difficult problem and established a proof-of-concept on a laboratory scale. With Styro-Filter, we can convert dirty waste into clean water!

## ***Styro-Filter Task Schedule*** **eCYBERMISSION**

<b>Week beginning</b>	<b>Task</b>	<b>Team Member</b>
8/2/2015	Review eCyberMission schedule. Brainstorm problems and solutions.	Everyone
8/9/2015	Tour Rumpke Recycling facility.	Everyone
	Identify problem of Styrofoam waste.	Everyone
8/16/2015	Research existing solutions for Styrofoam waste.	Everyone
	Search for experts to interview.	Lemonhead
	Research chemistry of polystyrene.	AlmondJoy
8/23/2015	Research Styrofoam/concrete blends.	Jujube
	Research recycling of polystyrene beads.	NestleCrunch
	Research mealworms to digest polystyrene.	Lemonhead
	Research Styrofoam insulation applications.	AlmondJoy
8/30/2015	Interview chemical engineering professor about the chemistry of activated carbon.	Everyone
	Prepare summary of existing solutions.	Everyone
	Search internet for activated carbon synthesis techniques.	AlmondJoy
	Additional research on polystyrene recycling.	NestleCrunch
9/6/2015	Review journal articles on activated carbon synthesis.	AlmondJoy
	Search internet for Styrofoam decomposition products.	Lemonhead
	Experiment with Styrofoam when exposed to solvents (acetone).	Everyone
9/13/2015	Experiment with densification of Styrofoam.	AlmondJoy/ Everyone
	Conference call with Dr. Alan Roy of Calgon Carbon.	Everyone
9/20/2015	Review with Battelle scientist about high temperature testing.	Lemonhead
	Prepare and submit densified samples for heat treatment in lab furnace.	Everyone
	Review polystyrene references.	Jujube/ NestleCrunch
9/27/2015	Review carbonization test results from Battelle.	Everyone
	Document test data in Google Docs.	NestleCrunch
	Strategize new techniques for carbonization.	Everyone
	Prepare densified samples for additional tests.	AlmondJoy
10/4/2015	Conduct carbonization tests in closed containers.	AlmondJoy
	Review results from carbonization tests.	Everyone

## **Styro-Filter Task Schedule**

### **eCYBERMISSION**

10/11/2015	Develop test plan for low temp heating.	Everyone
	Conduct low temperature heat treatments.	AlmondJoy/ Lemonhead
10/18/2015	Review results from carbonization testing.	Everyone
	Prepare calculations on carbon yields.	Jujube
	Contact professors to discuss results.	Lemonhead
	Prepare initial chemical etching experiments.	Everyone
10/25/2015	Additional chemical etching with phosphoric acid and potassium hydroxide.	Everyone
	Submit samples for BET test at Battelle.	Lemonhead
11/1/2015	Perform additional heat treatment tests.	AlmondJoy
	Submit new samples for evaluation.	Everyone
11/8/2015	Review BET test data.	Everyone
	Prepare prototype filter.	Everyone
	Investigate options for water contaminant measurements.	Jujube
	Request water testing at Battelle (testing didn't work out).	NestleCrunch/ Lemonhead
11/15/2015	Order Carolina Biological water test kit.	AlmondJoy
11/22/2015	Review additional BET test results and discuss implications.	Everyone
	Review data with OSU Chem. Eng. professor.	Lemonhead
11/29/2015	Perform water testing with Styro-Filter.	Everyone
	Review results of water testing.	Everyone
12/6/2015	Conduct patent search on activated carbon derived from polystyrene.	NestleCrunch/ Jujube
12/13/2015	Write Mission Folder (divide up sections).	Everyone
12/20/2015	Write Mission Folder.	Everyone
12/27/2015	Write Mission Folder	Everyone
1/3/2016	Work on figures for Mission Folder.	Everyone
1/10/2016	Work on figures for Mission Folder.	Everyone
1/17/2016	Review sections together.	Everyone
	Prepare bibliography.	Jujube
1/24/2016	Revise figures section.	Everyone
1/31/2016	Prepare summary video of Styro-Filter.	AlmondJoy/ NestleCrunch
2/7/2016	Prepare summary video of Styro-Filter.	AlmondJoy
2/14/2016	Present Styro-Filter at Stemfest at The Works Museum.	Everyone
2/21/2016	Final revisions of Mission Folder for submission.	Everyone








**Figure 1** Huge quantities of Styrofoam in landfills.

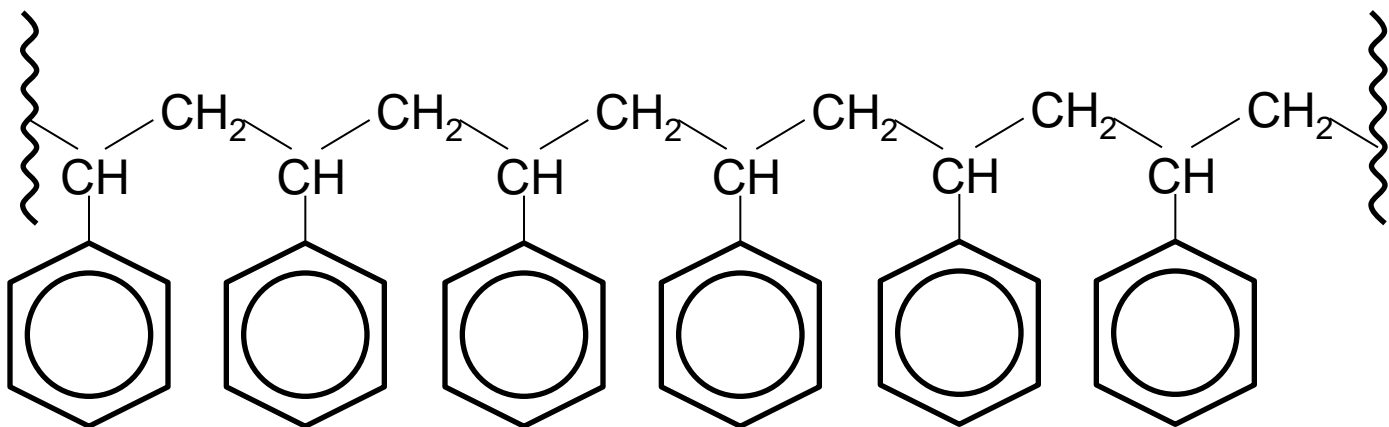


**Figure 2** Accumulation of Styrofoam on beaches.

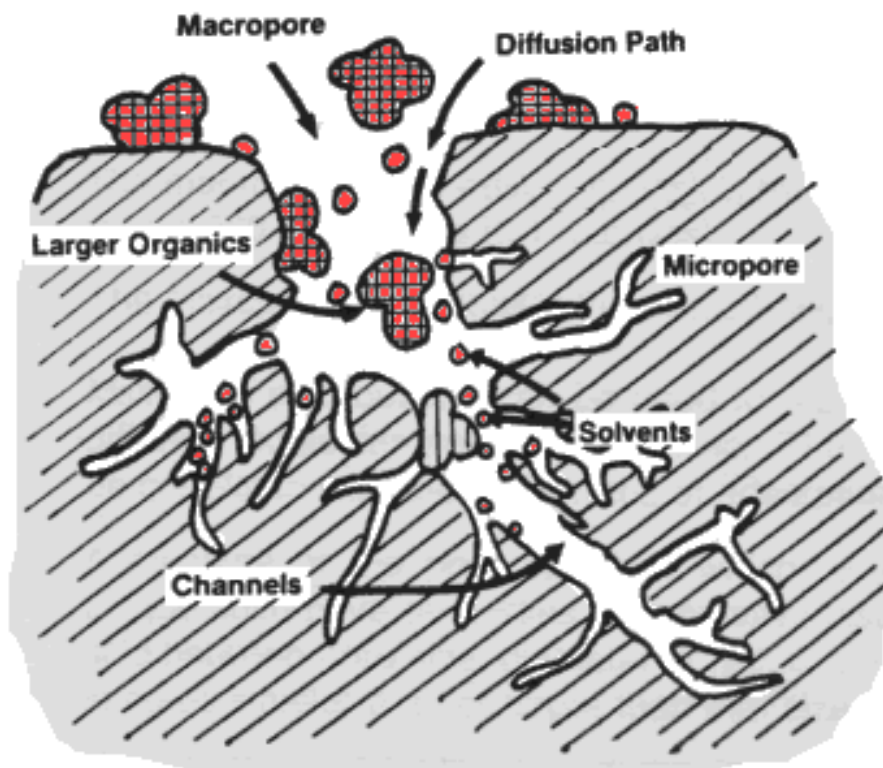


Solution	Drawback/Flaw	Example
Expanded Polystyrene Concrete	Low compressive strength. Tendency to crack.	
Reprocess or Re-use Polystyrene	Inefficient collection. No automated separation. Expensive processes.	
Decompose using Worms	Extremely slow and requires too many worms. Only 0.4mg/day per worm.	

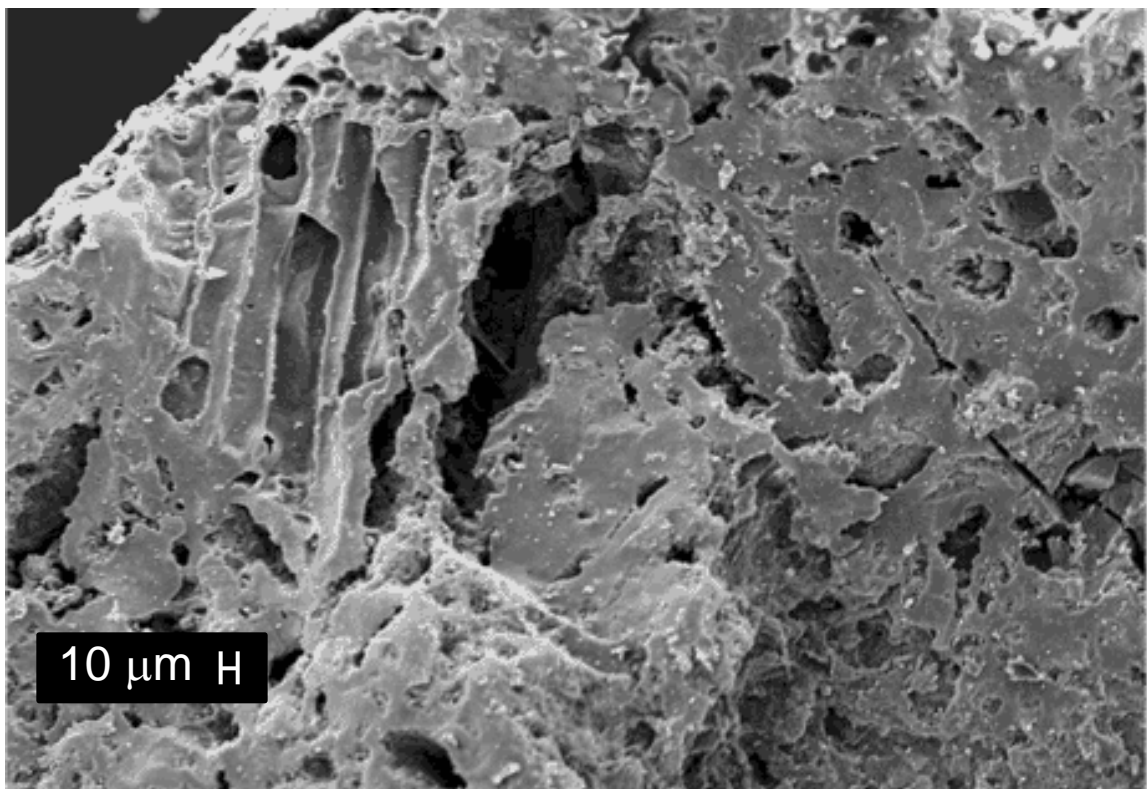
**Figure 3** Existing solutions for Styrofoam waste.



**Figure 4** Chemical structure of polystyrene ( $C_8H_8$ ).



**Figure 5** Schematic of activated carbon ([http://www.healthgoods.com/v/vspfiles/assets/images/activated\\_carbon\\_pores.gif](http://www.healthgoods.com/v/vspfiles/assets/images/activated_carbon_pores.gif)).



**Figure 6** SEM micrograph of activated carbon (<http://www.waterdrop.eu/adsoptionsverfahren>).



**Figure 7** Micromeritics ASAP 2020 Surface Area Analyzer at Battelle.



**Figure 8** Carolina Biological Water Test Kit.





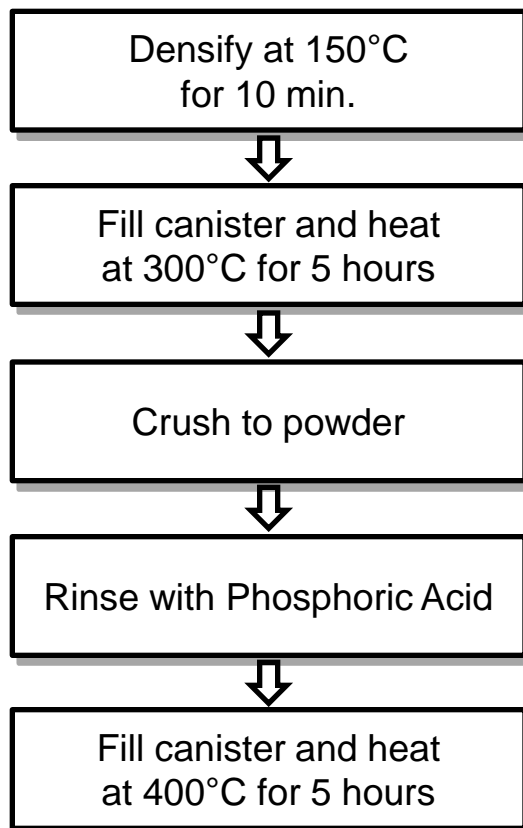
**Figure 9** Densified Styrofoam after heating at 150°C.



**Figure 10** Heat treatment experiments to evaluate carbonization yields.



**Figure 11** Carbonized polystyrene prior to etching.



**Figure 12** Process schematic to convert Styrofoam to activated carbon.

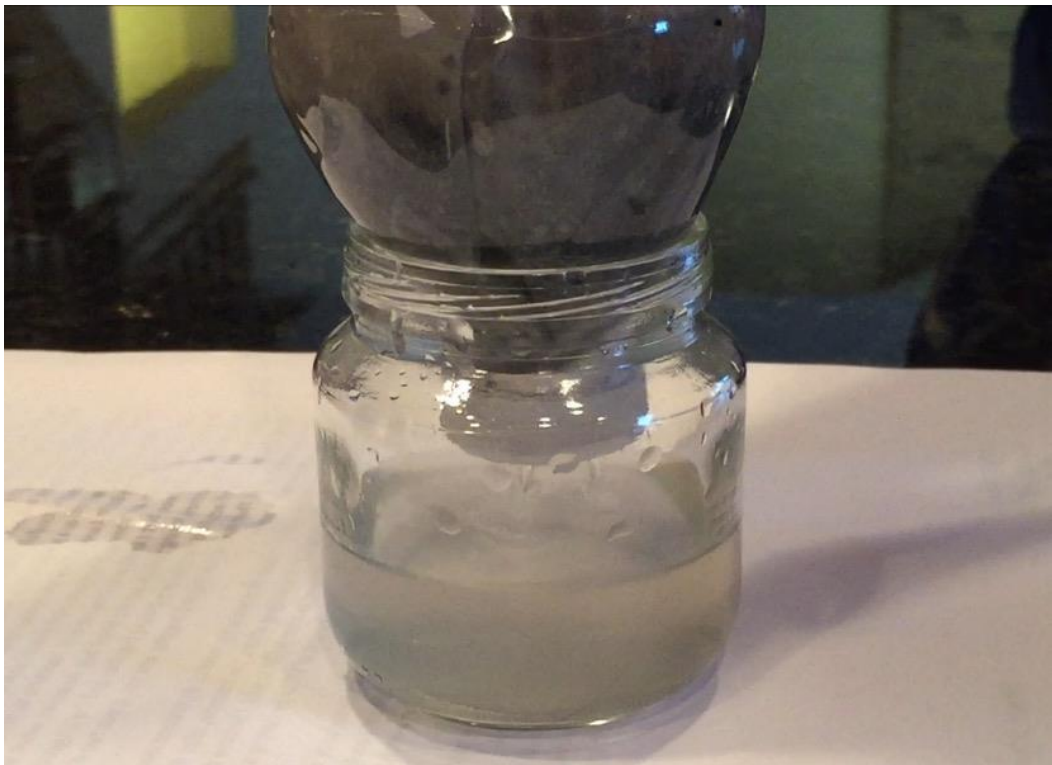


**Figure 13** Treatment with phosphoric acid to etch the carbon.

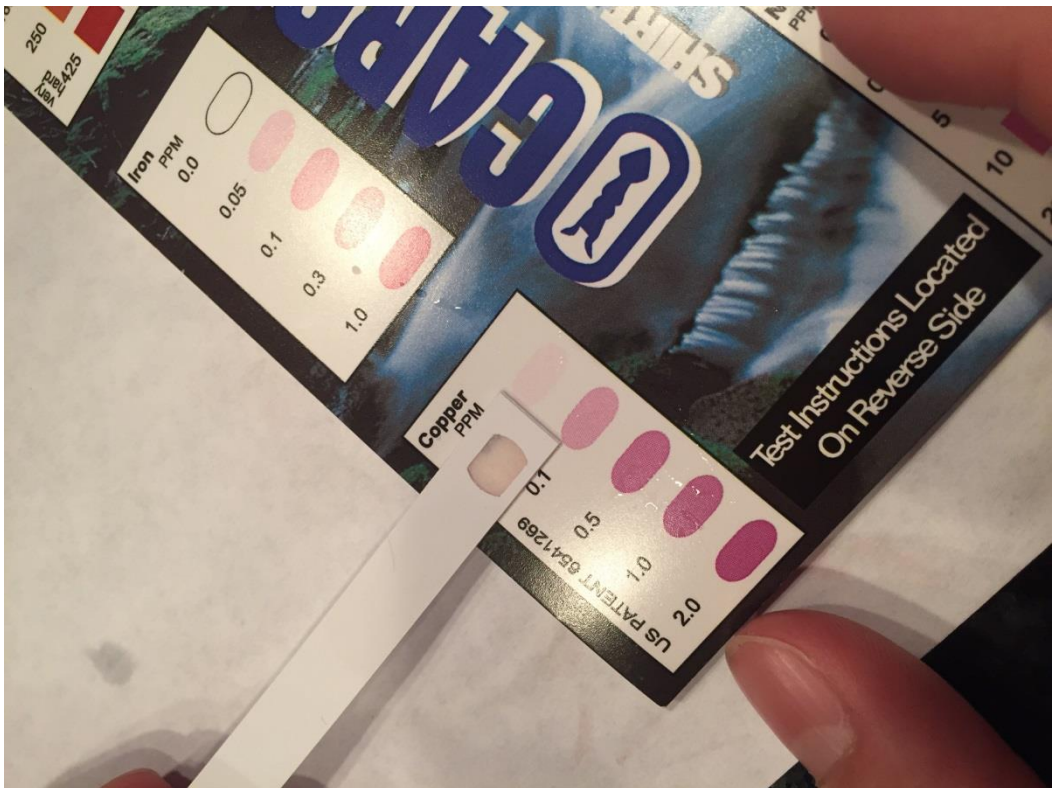
Test #	First Heat Treatment	Chemical Treatment	Second Heat Treatment	BET Surface Area	
1	800°C for 2 hours	None	None	Fail - Vaporized	✗
2	600°C for 2 hours	None	None	Fail - Vaporized	✗
3	500°C for 2 hours	None	None	Fail - Vaporized	✗
4	300°C for 5 hours	KOH	None	<1 m <sup>2</sup> /g	✗
5	300°C for 5 hours	KOH	700°C for 2 hours	Fail	✗
6	300°C for 5 hours	KOH	400°C for 5 hours	4 m <sup>2</sup> /g	✓
7	300°C for 5 hours	H <sub>3</sub> PO <sub>4</sub>	None	<1 m <sup>2</sup> /g	✗
8	300°C for 5 hours	H <sub>3</sub> PO <sub>4</sub>	700°C for 2 hours	Fail	✗
9	300°C for 5 hours	H <sub>3</sub> PO <sub>4</sub>	400°C for 5 hours	108 m <sup>2</sup> /g	✓

**Figure 14** Summary of experimental data with resulting surface areas.





**Figure 15** Filtering contaminated water with activated carbon product.



**Figure 16** Using test strips to quantify the amount of water contaminants.

Filter Media	Iron	Copper	Chlorine
None	1.0 ppm	1.0 ppm	5.0 ppm
Calgon Carbon (F-200 grade)	0.02 ppm	0.10 ppm	2.5 ppm
Styro-Filter	0.03 ppm	0.25 ppm	4.0 ppm

**Figure 17** Concentration of contaminants in water before and after being filtered through control (F-200) and Styro-Filter.