

CHE 451, Chemical Engineering Design II, is described in the NCSU course catalog as:

“Chemical process design and optimization. The interplay of economic and technical factors in process development, site selection, project design, and production management. Comprehensive design problems.”

“Comprehensive” is an understatement. The course challenges students with a wide variety of chemical engineering processes, ranging from biotechnology to energy to nanoscience. In addition, students complement their technical skills with teaming, leadership, project management, and communication skills. Both the instructors and the students feel an enormous sense of pride as we view the accomplishments of almost seven months’ work. We wish to thank those individuals and companies who have provided financial support or sponsored and advised projects this semester. The task of supporting and coaching these diverse projects and teams could not have been accomplished without their help!

Dr. Steven Peretti

Dr. Lisa Bullard

Organization Sponsors/Mentors

- Alditri Technologies
- Biogen Idec
- Biomufacturing Training & Education Center (BTEC)
- Cup A Joe
- Diosynth
- Engineering Entrepreneurs Program
- NC Solar Center
- Novozymes
- Port City Java
- Progress Energy
- Talecris
- Triangle Brewing Company

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- Michael Lowder (Eastman)
- Dr. Orlin Velev (CBE)
- Dr. Richard Venditti (Paper Science and Engineering)
- Rick Tufts (Triangle Brewing Company)
- Dr. Robert Kelly (CBE)
- Robin Hyde-DeRuyscher (Biogen Idec)
- Dr. Saad Khan (CBE)
- Dr. Sigma Mostafa (Diosynth)
- Dr. Tarek Aziz (NCSU Environmental Eng.)
- Ursula Webb (Talecris)
- Vanessa Rising (Novozymes)

Two-Minute Project Overviews
12:45 – 1:45PM, Room 1231, Engineering Building II

Board #	Title	Presenter
Clean Water Projects		
1	Design of a Water Pasteurization System for Rural Haiti	Justin McKenzie
2	Self-Powered Water Filtration Unit	Lauren Stanulis
3	Practical Water Purification for Rural Ghana	Stacey King
Biotech-Related Projects		
4	Optimization of a Microbrewery	Zach McDowell
5	Design of a Clean-In-Place System for Triangle Brewing Co.	Aaron Day
6	Evaluation of Disposable Technologies for the Clarification of Mammalian Cells	Dustin Stowell
7	Diosynth Disposables	Natalie Soto
8	Design of a Manufacturing Process for Factor VIII Protein Purification for Talecris	Chris Austin
9	Novozymes Pilot Plant Project	Kyle Ford
Energy-Related Projects		
10	Enzymatic Biodiesel	Zachary Conrad
11	Design of an Algae Biomass and Harvesting Facility	Patrick Parr
12	Coffee Grounds to Biodiesel	Derek Henderson
13	Extremely Thermophilic <i>Caldicellulosiruptor saccharolyticus</i> for Biohydrogen Production	Jeffrey Poley
14	Converting Paper Sludge to Ethanol	Ben Donnalley
15	Acetic Acid from Coal	David Rhoden
16	Ammonia Mitigation Technologies	Jeffery Preece
17	Atomic Layer Deposition Reactor	Kevin Nance
18	Design and Engineering of Microbial Gas-Phase Carbon Absorbers for Power or Cement Plant CO _x Emissions	Daniel Peele
Product Design		
19	Cholera Surveillance of Drinking Water in the Developing World	Sindhu Sevala
20	Liquid Body Armor	Peter Venema
21	Microfluidic Biosensor	Michael Brown
22	Decontamination Packet Design	Elizabeth Butler

1:45 – 2:55PM **Poster Session (First and Second Floor Atrium of Engineering Building I)**

3 – 3:30PM **Closing Remarks and Special Recognition (Room 1231, Engineering Building II)**

Board Number: 1

Design of a Water Pasteurization System for Rural Haiti

Rob Ballard, Katherine Hoeferkamp, Justin McKenzie, Austin Smith

Advisor: Dr. John van Zanten

Water contamination is a leading cause of child mortality worldwide. Dirty streams and rivers, especially in rural areas are the main sites of infection. The goal of this project was to divert water from a contaminated stream and produce 300 L (80 gal) of potable water for 300 children living outside the village of Le Gressier, Haiti.

The water produced would meet the World Health Organization's standards for safe drinking water. The properties of contaminated water in Haiti were studied to better understand what should be targeted for removal specifications. High turbidity and pathogen concentration posed the greatest challenges in designing a pasteurization system. A two-part system has been proposed which incorporates filtration to reduce turbidity and a heating chamber to minimize the number of active microorganisms. Based on Haiti's available and renewable resources, solar radiation was chosen to be the sole energy source used. After research and experimentation, it was determined that this goal could be achieved through sedimentation, filtration and pasteurization.

Turbidity, the opacity of water due to suspended particles, was the first main challenge. Using sedimentation and filtration processes the challenge was met. It was found that a 1.0 m (3.3 ft) deep, 750 L (198 gal) settling tank and a 0.9 m (3 ft) tall filter with a 0.344 m (1.13 ft) diameter can reduce turbidity to the WHO levels required.

Pasteurization is a process that uses heat to kill pathogens in liquids. Pasteurizing water to 65°C (149°F) for six minutes removes 99.9% of pathogens. A 3.0 m² (32 ft²) rectangular apparatus called the hotbox is used to collect solar energy and transfer it to a shallow water depth of 0.025 m (0.0820 ft) in batches. 300 L of water can be pasteurized in four batches. The pasteurization process was made efficient by an energy recovery process and an insulating enclosure.

It was found that the top plate of the hotbox is the driving force in heat transfer and that its temperature determines the warmth of water and the speed at which water is warmed. This being the case, it is recommended that simple temperature experiments confirm the typical operating plate temperature. It is hypothesized that a plate temperature of 90°C (194°F) will ensure the sterilization temperature of 65°C will be reached inside the hotbox.

Further optimization of this design is also recommended to increase daily water output. The focus of future work should be on outside experimentation with a model more similar to the proposed design, maximizing the effectiveness of the heat exchanger, and minimizing the total cost of the unit. This design could be used in Haiti and other under-developed nations with similar energy and water quality issues.

Board Number: 2

Self-Powered Water Filtration Unit

Michaela Bennett, Luisa Islas, Lauren Stanulis, Autumn Place

Advisor: Dr. Tarek Aziz

Anaerobic digestion is a means of obtaining usable energy from organic waste by breaking down organic matter to form biogas. Biogas is a mixture of methane and carbon-dioxide that can be used as an energy source similar to natural gas. This report investigates the potential applications of anaerobic digestion in disaster situations and remote locations. The goals of the project are to produce an energy source that powers a drinking water purification system and provides a sanitation solution.

The system designed in this project could be implemented in almost any refugee situation, however, the focus of this project is the Kakuma refugee camp located in Kenya. All of the calculations performed and design considerations made were based on information related to the size and population of this specific refugee camp.

The kinetics of the anaerobic digestion system provided important information regarding the amount of biogas that can be produced, and how microorganisms and biomass decay over time. Using kinetic equations, many of the processes involved in anaerobic digestion were modeled. These models were converted to a Matlab code that with the correct initial conditions can provide growth and decay data as well as biogas production for this designed system. The model can also be used to make predictions on other systems where the conditions are known.

Information from kinetics as well as biogas production data was used to design the process.

Along with electrical and heat energy production, the effluent from the reactor can be land applied. Land applied biosolids can be utilized as fertilizer once pathogens and volatile solids are reduced to levels compliant with the EPA's 40 CFR Part 503. Anaerobic digestion helps to accomplish such reduction and to ensure user safety, composting will be used as a follow up treatment. Composting will occur for 3 to 4 weeks and once land applied direct contact should be avoided for 30 days.

A total of 8 miles of stainless steel piping for gas as well as 3 miles of water piping will be needed to support the system. Bladders are located along the perimeter of the refugee camp to provide easy access for the refugees. Tanks for collection of dirty water as well as retrieval of clean water will be located centrally in the camp.

Shipping analysis shows that in order to supply the Kukuma refugee camp with a kit that includes of the supplies necessary to build a water purification system powered by biogas, twenty 40' ISO standard shipping containers would be needed. The system would cost over 2.5 million dollars. Most of this cost is due to the expensive nature of the bladders used for anaerobic digestion.

Board Number: 3

Practical Water Purification for Rural Ghana

Stacey King, William McDanel, Jacob Thelen, Cynthia Warren

Advisors: Dr. Alex Hobbs, Dr. Charles Joyner

The development of a low cost solar distillation kit has been proposed to provide clean drinking water to people in remote areas of Ghana. Currently, 9 million of Ghana's 19 million people lack access to potable water. Many of these people reside in rural areas where the lack of infrastructure prevents the implementation of large-scale, energy intensive water purification technologies, such as flash distillation or reverse osmosis (Engineers, 2009). Although simple techniques, such as chemical treatment and filtration, can be used to disinfect water, solar distillation is able to disinfect water as well as remove harmful chemicals.

Unfortunately, the conventional method of solar distillation, which has been plagued by poor efficiency and high capital costs, requires significant developmental breakthroughs before it will be a feasible technology. Many previous studies have been successful in testing modifying solar still designs in order to increase efficiency and determine the optimal still operating conditions; however, no design has yielded a feasible option for widespread use. Based on these studies and an analysis of the system's energy and material balances, a number of prototypes were built and tested in an attempt to determine the most cost effective design for a solar still kit.

Three different one-third scale prototypes were built and tested. Due to climate differences between North Carolina and Ghana, the prototypes were constructed to evaluate the relative improvements achieved by each modification. Accordingly, the first prototype was modeled after the most basic solar still design and was intended to serve as a control. The second prototype tested the benefit of adding a continuous feed tank into the system. Lastly, the third prototype explored the feasibility of adding an external condensing module to the continuously fed prototype. Also, in order to explore alternative building materials, a small clay bowl was built and sealed with paint to test the feasibility of using clay to construct the still basin.

Of the three prototypes tested, only the second prototype delivered measurable results; therefore, results of the relative improvement tests were inconclusive. Nonetheless, a great deal of useful information was gathered during the construction process and through observation of solar still operation. Accordingly, the proposed kit was designed to take into account the complexities observed during construction, specific weaknesses observed during operation, and the economic benefits of any modifications. The general form of the kit was specified, which includes a reusable mold for concrete casting; paint to seal the concrete (or clay) basin; a preformed collection trough; glass; and the necessary tools for construction. Finally, a preliminary cost analysis of the kit components was performed and a scenario where the kit could be economically feasible was established; however, the details of how the kits will be produced and implemented remain undetermined.

In order to optimize the kit design and gain a better understanding of its implementation, the construction of a full-scale unit should be pursued. Through the construction of a full-scale model, the exact dimensions of the concrete mold could be determined, and the construction process would yield further insight that could be used to simplify the overall kit design. Also, future studies should further explore the economic feasibility of manufacturing and implementing the solar still kits.

Board Number: 4

Optimization of a Microbrewery

Megan Bittner, Zach McDowell, Scott Peacock, Andrew Waltersdorf

Advisors: Dr. Jan Genzer, Andy Miller, Rick Tufts

Several modifications were designed to optimize the pilot-scale brewing system that was previously constructed for Triangle Brewing Company by an earlier NC State Chemical Engineering design team. The pilot system allows new recipes to be tested at a small scale so that resources are not wasted operating the full scale system. In order for the pilot system to be a practical asset to the brewery that is used regularly, the system must function as closely as possible to the primary system. This involves ensuring repeatability of the product that is to be scaled up. Another goal that was set when redesigning the pilot system was to alleviate several labor intensive aspects of operating the system. Taken collectively, constructing a small scale system that can be easily operated while maintaining the accuracy of the batch was the overall objective of the group.

Upon discussing this objective with Triangle Brewing Company, the first decision that was made was to improve the temperature control of the system. The maintenance of a constant temperature is very important during many steps of the brewing process. The new temperature control system that was designed utilizes a customized mixing of hot and cold streams. The flow rates of the streams can be set to attain the correct water temperature when laying the mash. The mixed streams also use the hot water more efficiently reducing heating times and wasted energy inputs. Given the scope of the project and the time frame available, additional modifications were also designed to further improve the pilot system. Another large alteration was the addition of a hopper that allows the water and grain to mix evenly before they enter the mash tun. The mounting of the hopper into the lid of the mash tun acts to reduce heat loss so a proper strike temperature can be achieved. The heat exchanger was also redesigned to include four 15 ft coils as opposed to a single 50 ft coil. This alteration has greatly improved the cooling time of the mash kettle. A few other minor system modifications were developed with the intention of improving the versatility and ease of operation of the system, including fabrications to the housings of the hot liquor tank and mash kettle.

Data were recorded with the newly designed improvements for the equipment, and compared to the unaltered system to provide baseline information on how the system performed previously. Calculations were also performed to predict the improvement that could be made by redesigning the heat exchanger. This offered a means for comparison when similar readings were taken after the modifications had been constructed and implemented. The largest advancement in the pilot system's performance that was made was the reduction in the man hours required to brew a batch on the system. This coincided with an easier more systemized operating procedure. Each of the three major alterations to the system proved to be upgrades over the previous design. The temperature control system saved hot water for future steps while maintaining constant water temperatures and the hopper uniformly combined the grain and water creating an even temperature distribution. Lastly, the heat exchanger turned out to be one of the most effective changes that was made as the cooling time of the mash kettle was made roughly four times shorter.

Board Number: 5

Design of a Clean-In-Place System for Triangle Brewing Company

Aaron Day, Jordan Smith, Peter Grochowski, Brian Gensch

Advisors: Dr. Jan Genzer, Andy Miller, Rick Tufts

This report will outline the process and structure of a CIP system that will effectively clean and sanitize the fermentation tanks used in the brewing process of the commercial microbrewery, Triangle Brewing Company. The system will be efficient and mobile, resulting in increased cleanliness and flexibility, as well as time and material savings. The industrial sponsor for this project is Rick Tufts, master brewer at Triangle Brewing Company. He has assisted the project team through out the design process by using his professional expertise to help guide the direction of the project.

The CIP process that will be implemented involves two separate cleaning agents: dilute sodium hydroxide as an alkaline cleaner, and dilute peracetic acid as a sanitizer. Sodium hydroxide was chosen for its effectiveness in dissolving organic compounds and low foaming characteristics. The sodium hydroxide solution will be heated to 150 °F using a small hot water heater in order to optimize its effectiveness. Peracetic acid was chosen as the sanitizer because of its high oxidation potential and low foaming characteristics. The process will be run in cycles: first the sodium hydroxide will run, followed by a water rinse, and finally the peracetic acid sanitization cycle. A 1.5 horsepower pump will be used to pump the solution into the tank through the spray ball inlet attached to the fermentation tank. A second pump, external to the CIP skid, will be used to circulate the cleaning solutions inside the tank and then recycle the solution back into the appropriate reservoir. The wastewater resulting from this process will primarily come from the use of sodium hydroxide. Due to the fermentation process, most of the waste removed from the tanks is comprised of dead yeast cells. These dead yeast cells contribute to high Biological Oxygen Demand (BOD) levels. BOD levels should be held under the regulatory limit of 5 mg/L as they are broken down by the sodium hydroxide. This process produces phosphates, but phosphate levels should also be below the legal limit for Durham, NC. Peracetic acid has no negative effects on the environment and is safe for disposal.

After several design revisions and a lengthy construction phase, the CIP skid is fully operational. Functional testing has led to the development of operational procedures that are intended to advise the operator on safe and effective use of the system. An economic analysis of the costs associated with current cleaning practices and CIP technique show a possible savings of approximately \$660 annually. The initial budget request for the project was \$1,290 and the actual expenditures for the project totaled \$1,173. The project was completed under budget, and could potentially pay for itself in cleaning material savings in less than two years. Capital costs were reduced in several ways. Triangle Brewing Company provided the external pump and hot water heater, and copper piping was determined to be an acceptable substitute for stainless steel. These capital cost savings made the project economically feasible.

Board Number: 6

Evaluation of Disposable Technologies for the Clarification of Mammalian Cells

Toby Blackburn, Juan Castaño, Tyler McCaw, Dustin Stowell

Advisors: Marcelo Anderson, Robin Hyde-DeRuyscher

The goal of this project is to design a feasible, disposable alternative to the stainless steel centrifuge process currently used in Biogen Idec's cell culture clarification. This goal is being driven by the increasing interest in disposable processes and cost reduction of the current process. Included in the considerations are qualifications such as turnaround time, remote manufacturing capability, and capital equipment cost.

Numerous candidate technologies were reviewed for this application. Technologies were evaluated by standards developed to meet the criteria of the problem statement. These criteria are:

- Disposability
- Process Costs
- Reduction of Particulate
- Contamination Risk
- Product Stability
- Risks (Process, Economic, Regulatory, Technological)
- Capital and Development Costs
- Waste Streams

After applying these criteria to the candidate technologies, an overall ranking was established. This ranking determined which technologies would proceed with experimentation. The technologies selected were:

- Settling/Precipitation
- Tangential Flow Filtration
- Feedback Filtration
- Disposable Centrifugation
- Expanded Bed Chromatography

After carrying out experimentation, designing each system, and costing out each process, score card analysis was utilized to determine the most suitable process. A weighting factor for each category was determined, and all table inputs were converted to a 1-10 scale, with 1 being an ideal process. The scores were then multiplied by the weighting for each category and summed to obtain an overall score. The score card analysis results indicate that tangential flow filtration is the best process given our design criteria. After also considering the fact that expanded bed adsorption replaces a chromatography step as well, the results still pointed to tangential flow filtration as being the best option.

Board Number: 7

Diosynth Disposables

Veronica Adams, Arouna Liloudini, Natalie Soto

Advisor: Dr. Gary Gilleskie

The purpose of this project is to propose the integration of disposable technology to an existing monoclonal antibody (mAb) production line with a cell culture scale of 2 x 110 liters designed by Diosynth Biotechnology. Diosynth's ORCA mAb has a molecular weight of 147076.56 and an isoelectric point of 8.68.

A cost analysis was performed to determine the overall economic impact of utilizing various disposable technologies at different unit operations along the production line. Current manufacturing techniques typically employ stainless steel equipment that must be cleaned using sterilization-in-place (SIP) and clean-in-place (CIP) infrastructure, resulting in significant cost and time for cleaning and sanitizing the equipment. In recent years, great advances in disposable technology, which reduce the need for cleaning, sterilization and sanitization steps, have allowed the pharmaceutical industry to improve efficiency while reducing overall costs. Although few studies have considered a completely disposable process, life cycle costs have been analyzed for partially disposable processes (Barnoon & Bader, 2008).

This mAb production process begins with Chinese hamster ovary (CHO) cells that are expanded through a series of shake flasks, seed reactors and final production bioreactor. In the bioreactor, the CHO cells produce and secrete mAb, which is then sent downstream for purification. The downstream process begins with centrifugation and depth filtration for removal of host CHO cells. The mAb in the resulting clarified cell culture supernatant undergoes purification in a Protein A Affinity chromatography column. After passing through a low-pH viral inactivation step, the mAb is further purified by cation and anion exchange (CEX and AEX) chromatography. The protein passes through a virus-removing filter prior to entering the ultrafiltration/diafiltration (UFDF) unit, where the product stream is concentrated and exchanged into phosphate buffer solution. The product passes through a final 0.2 µm filtration as part of the bulk fill.

To simulate the production of the Diosynth mAb, SuperPro Designer has been used. The SuperPro simulation was made for an entirely "fixed" system for the purpose of evaluating operating costs and comparing those costs to a disposable process. For the purpose of this project, a fixed system is referring to a process with little or no disposable options. The model was then integrated with disposable components for each unit operation where available. Disposable options are offered for seed and production bioreactors, centrifugation, all filtration steps, viral inactivation, ion exchange chromatography and the UFDF step. The most desirable component was chosen for each unit operation based on effectiveness or availability. The cost for each disposable were obtained from vendors and used for the disposable operating cost analysis. The disposable process was compared to the fixed process for the overall operating cost and time savings on a per run basis. The same scenarios were then expanded to a clinical campaign basis. A five run campaign was chosen to better meet the needs of Diosynth, a contract manufacturer. Additional analyses were completed in SuperPro to determine water cost sensitivity and the efficiency of cycling expensive CEX membranes to find the most beneficial combination of fixed and disposable equipment.

After thorough water cost sensitivity and cycling analysis, the conclusion is that a partially disposable process with a fixed CEX column is the most cost effective combination of disposable technology for the 2 x 110 liter process.

Board Number: 8

Design of a Manufacturing Process for Factor VIII Protein Purification for Talecris

Christopher Austin, Divine Edem, Shanna Martini

Advisors: Marcelo Anderson, Hao Lieu, Ursula Webb, Dave Wolozyn

Each graduating chemical engineering class from North Carolina State University is challenged with the task of designing an innovative, socially-relevant, and realistic project utilizing professional engineering methods. This capstone project is intended to employ all of the skills and knowledge sets gained from the student's undergraduate curriculum. Projects vary widely from chemical reactions, facility optimization, product development, etc. They are all, however, representative of the current abilities of the participants and intended to immerse students in design conditions that would be expected of them in their upcoming professional careers. The project presented herein is sponsored by Talecris Biotherapeutics Corporation, located in Clayton, North Carolina, through collaboration with the Biomanufacturing Training and Education Center of North Carolina State University.

The three students participating in this project are challenged with the task of designing a manufacturing process for Factor VIII protein concentrate. This particular protein is an essential factor in the blood coagulation pathway of the human body. For persons lacking this protein, the body is unable to provide necessary coagulating proteins that clot blood. This disorder is known as Hemophilia A and affects approximately 400,000 people globally. The effects of Hemophilia A can be countered, however, by administering highly concentrated therapeutic drugs containing Factor VIII in solution.

The document presented herein is the final submission to N.C. State faculty and Talecris mentors. Following research of various unit operations and data analyses, a conceptual manufacturing process has been designed to yield a FactorVIII:vWf concentrate. The document outlines the processing of fresh frozen blood plasma to fill/finish. This includes, in order:

- Two-step precipitation with PEG 4000, with disc-stack centrifugation of liquids/solids
- Solvent/Detergent treatment of solubilized product to inactivate enveloped viruses
- Depth Filtration for clearance of non-enveloped viruses and potential prion contaminants
- Anion exchange chromatography for purification and capture of FactorVIII:vWf complex
- Size exclusion chromatography for further purification and solvent/detergent removal
- Ultrafiltration for concentration/reformulation
- Lyophilization for filling – design outside scope of project

Each unit operation is researched and justified in the corresponding section. Additionally, purchase costs for major equipment and raw materials are included for an approximate estimate of the process. Considerations are proposed for a facility production layout, including personnel flow and operational segregation. Recommendations for a path forward are made at the end of the document. This process should yield a safe, effective, and economically viable product.

Board Number: 9

Novozymes Pilot Plant Project

Karen Achtyl, Kyle Ford, Jakob Skjold-Jorgensen, Jonathan Sokash

Advisors: Marcelo Anderson, Gian Oddone, Vanessa Rising

The goal set forth by Novozymes was to improve the capability of existing and future process development activities. The Novozymes design team created both an efficient and easy to use, new green field pilot plant for Novozymes. In addition, the design team also tried to modify the existing pilot plant to be more efficient in retrofit designs. The current and future pilot plant will be utilized for scaling and process development purposes. This final report includes a comparison of the cost and efficiencies of the existing, retrofit and green field pilot plant designs. This will enable Novozymes to determine which one is the best option for their needs.

In the beginning of this semester, our focus was devoted to developing options and designing the layout of the plant. First, we created drawings and layouts for a possible pilot plant. Afterwards, we discussed the potential problems with the placement of equipment including hazard points, cleanliness and congestive areas. Understanding the processes that occur in the pilot plant was paramount to understanding the usefulness of certain equipment and exactly the ideal placement of it. Next, we evaluated information to determine the best devices for the plant. This included the size and capabilities of the bioreactors as well as the analytical equipment that would be required for operation.

The main focus of this project was to develop a new design for Novozymes pilot plant. We explored various options and selected the equipment best suited for the type of organisms that Novozymes uses. A wide variety of ranges were used in calculating the most versatile pilot plant. A description of analytical equipment to be used is included to understand the functions and what advantages can be obtained when using this equipment. In the designing process, we discovered that a mixture of sizes and materials for the bioreactors will allow a greater amount of versatility in the pilot plant and therefore potentially a higher throughput. Additionally, analytical equipment was chosen so that on-site sampling can be as useful as possible.

In this final report, we included not only the new plant design, but also three different retrofit designs that can be applied to accompany the existing plant. These options are less costly and will still provide Novozymes with needed improvements to their pilot plant. The retrofit designs were created with input from operators of the plant and were inspired by their continuous problems with certain aspects of the plant such as poor placement of meters and long turn-around time. Each design is a bit more complex than the next, but other inexpensive features with added ease of use can be chosen to be included with any of these designs, together with the one already in place.

Finally, an economic analysis was conducted to include everything in the new design. Another comparison of throughput, versatility, man-power required and overall cost was also conducted between the existing, new and retrofit designs. In addition, a graph stating the number of options that can be fulfilled for a specified dollar amount is included. This analysis allows Novozymes to view the benefits and disadvantages of each design.

Enzymatic Biodiesel

Zachary Conrad, Yasir Rashid

Advisor: Dr. Steven Peretti

A new technology based on a novel immobilized enzyme will be used to design a production facility capable of producing 2 million gallons of biodiesel per year. Students at North Carolina State University will be evaluating the production of biodiesel from oil-methanol transesterification. A pilot scale reactor for enzymatic biodiesel production has been built by North Carolina State University student Marshall Bowden. The fungus, *Rhizopus oryzae*, expresses high lipase activity and is the catalytic source for the full scale reaction system. Generating optimized growing conditions (media composition, support bio-particles, temperature) for the fungus in the pilot scale reactor is a primary goal for the enzymatic biodiesel process. Conditions for generating maximum biodiesel production were varied, including temperature, excess methanol, and reaction time. Results were used along with tradition process information to design the production facility.

With the design and construction of the pilot scale reactor already in place, the project requires that conditions of the reactor functionality be known. This has been achieved through small scale experimentation regarding *Rhizopus oryzae* growth as well as transesterification of oil into biodiesel. The media composition for optimal growth was determined to include the following per liter of aqueous solution: 70 grams peptone, 1 g NaNO₃, 1 g KH₂PO₄, 0.5 g MgSO₄, and 10 g glucose. This composition allowed for the growth of cellular mass. Bacterial growth was present in early testing and was problematic for fungus cultivation. Proper sterilization techniques were reviewed and implemented. It was discovered that the bio-blocks designed for cellular immobilization required multiple chemical washings (acidic ~3 pH and basic ~10 pH) to ensure no bacterial contamination. These modifications allow for the growth of *Rhizopus oryzae* samples. Transeserification was then carried out on 50 and 100 mL volumes of oil and excess molar methanol additions. The pilot reactor was also modified. Marshall Bowden's initial design required some modifications to ensure proper functionality for fungal growth and transesterification. A feed line was introduced inside the system to provide better mixing conditions to the reactor column. Diffusing oxygen into the system was improved from a bubbling tube to a disk diffuser which provided better aeration and lower agitation. This generated a more stable environment for fungal growth while improving mixing conditions within the reactor column. A pressure relief valve as also augmented to properly displace any liquids escaping the vessel. Maintaining internal temperatures for the fluid was solved by enclosing the pilot reactor in a construction grade plastic sheeting of thickness 38.1 μm. Inside the rectangular enclosure, a 1500 W oil filled radiator was added to maintain temperatures within the reactor between ~30-40°C.

Upon running the pilot scale reactor, bacterial contamination occurred during the two runtimes. Methods for media and inoculums transfer were modified to reduce instances for contamination. The content of methyl esters was investigated for small runs as well as the pilot reactor operations. GC results showed conversion rates ranging from 0.78% to 3.66% with a maximum convergence of almost 9% for small scale studies. Negligible conversion occurred while running the pilot reactor. It is believed that the contamination caused a pH change of the media (from pH~5.6 to pH>9) and interfered with lipase production and/or activity. Qualitative testing of lipase immobilization was performed using SDS PAGE. Proper protein weights for *Rhizopus oryzae* lipase were determined to be 31kDa and 34kDa. Results testing media (no fungus), broth (with fungus), and cell walls showed that lipase was not released to the media upon incubation after 84 hours.

Design of an Algae Biomass and Harvesting Facility

Alex Hunt, Patrick Parr, Brad Reese

Advisor: Dr. Steven Peretti

An increase in fuel prices and greenhouse gas emissions has caused a rising concern for a renewable and economical alternative fuel. Biodiesel, a fuel produced from plant oils, is capable of satisfying each of these concerns by recycling carbon emissions and possibly providing a cheap diesel substitute. However, using food crops in the production of fuel generates a food vs. fuel dilemma causing a possible decrease in food supply. This problem can be eliminated by the use of a feedstock which is not part of the food market, such as algae.

Algae have high lipid content along with a high growth rate, making it a desirable crop for biodiesel production. Algae can be grown in areas which are unsuitable for other crops allowing an even further separation from the competition of food and fuel. Algae also utilize carbon dioxide emissions through its production, therefore limiting new accumulation in the atmosphere.

This project focused on using a previously constructed photobioreactor to grow algae and develop the optimal operating conditions necessary to efficiently produce algae. The reactor produced a maximum steady-state concentration of 0.86 g L^{-1} , and achieved a yield of $\sim 6.45 \text{ g day}^{-1}$.

Flocculation and centrifugation tests were performed to evaluate the effectiveness of each dewatering method. The flocculation experiments using aluminum sulfate removed 97 % of the water while recovering 95 % of the algae. The disk stack centrifugation recovered 99 % of the algae and produced a paste containing 85 % solids.

A material balance and economic analysis were implemented to determine the profitability of a biodiesel facility using algae oil as its feedstock. Based on the growth data and using flocculation to harvest the algae, the facility would not be economically feasible. However, operating at a concentration of 4.5 g L^{-1} was determined to be the point that if lipid extraction was of no cost the process would break-even.

Several methods could be altered to help optimize the facility; these improvements could be either of economical benefit, or operational benefit. In order to make an algae-to-biodiesel facility economically reasonable numerous methods can be investigated. First, the synthetic media may be replaced with chicken litter, which contains high amounts of the required nutrients, at a much lower cost. Also, in order to minimize the risk of harmful organisms take over higher salinity concentrations need to be used. Polymer flocculants may be tested in conjunction with the inorganic flocculants, tangential flow filtration should be looked as an alternate harvesting method.

Coffee Grounds to Biodiesel

Derek Henderson, Matt Hudson, Erik Mitran, Jodi White

Advisors: Dr. Steven Peretti

Increased demand for energy has necessitated the search for alternative fuel sources, such as biodiesel. Recent research by Kondamudi suggests the oil from spent coffee grounds could be a potential feedstock in the generation of biodiesel (2008). In this project, the potential use of spent coffee grounds as a feedstock for biodiesel is investigated. Feedstock availability, ethanol as a green alternative for oil extraction, and economic feasibility in using spent coffee grounds are all addressed in this report.

The coffee market in the Research Triangle Area (RTA) was surveyed to determine the local supply of spent coffee grounds. From the survey, it was determined each shop used approximately 20 lbs of dried coffee grounds per day. There are approximately 1,500 coffee shops in the RTA, which can generate ~30,000 lbs of dried coffee grounds daily. This assumes the demand for coffee grounds remains constant everyday of the week. Therefore, it is assumed a sufficient supply of spent coffee grounds is available for biodiesel production.

After analyzing the supply of spent coffee grounds in the surrounding RTA area, research began on a technique to extract the coffee oil from grounds. Currently, solvent extraction using hexane is predominantly employed. However, with increasing green engineering trends and health factors, ethanol surfaced as a potential green alternative. Using ethanol as the solvent of choice, lab experiments were performed varying temperature, time, and volume of ethanol. The experiments indicated temperature had no great influence on the amount of oil extracted while the length of time and volume indicated otherwise. The experiment indicated optimal oil extraction required an ethanol to dried grounds weight ratio of 2.63:1 and an extraction time of 2 hours. Reactive extraction using 1.5 wt% potassium hydroxide and ethanol was performed. These trials showed similar results to separate ethanol extraction and transesterification reaction. Therefore, an economic comparison of these cases was completed.

Using the extraction parameters, a SuperPro design was modeled for three potential cases. The three cases were compared using SuperPro simulation to determine which case was most economical, while maintaining efficiency. From the three cases evaluated, the recommended design of the facility has an approximate capitol cost of \$177,440 and operating cost of \$551,198. From the cost analysis and revenue generated, it was determined a positive annual net profit of \$37,879 could be attainable. The production of ethanol, from waste grounds, on-site through fermentation could greatly reduce the operating cost; therefore, increasing the annual net profit.

Board Number: 13

Extremely Thermophilic *Caldicellulosiruptor saccharolyticus* for Biohydrogen Production

Matt Edds, Natalie Patterson, Jeffrey Poley

Advisors: Dr. Robert Kelly

As a consulting firm, HydroGEN has been asked to design a demonstration scale plant that produces hydrogen gas from a cellulosic feedstock via the anaerobic thermophile *Caldicellulosiruptor saccharolyticus*. The system has been designed entirely and the cost effectiveness of building such a plant has been evaluated with respect to the cost of construction and operation, and compared to predicted trends in the cost of hydrogen.

Concerns of climate change and dependence on foreign oil have led to a great deal of development in the field of alternative fuel sources. Hydrogen is being explored as one such fuel, as hydrogen fuel cells produce only water as a by-product, and could decrease the total volume of oil imports required for the country. Thus, the motivation of this plant design is to capitalize on this area of development by providing a method in which hydrogen may be produced at a cost that makes it competitive with traditional fuel sources derived from hydrocarbons.

The feedstock to be used for the specific design is switchgrass with minimal pretreatment, involving addition of water in a 3:1 hydration to feedstock ratio. The feed is to be charged to an anaerobic batch reactor containing *C. saccharolyticus*. The reactor will be operated for approximately twenty-four hours per cycle at atmospheric pressure and 70 °C, leading to a nominal conversion of 90% of the initial cellulose and hemicellulose. In order to prevent dissolution of carbon dioxide and hydrogen in the reactor solution and allow the gaseous products to be continuously treated, nitrogen will be continuously sparged through the reactor. In addition, water will be added to the reactor in order to replace the water consumed by the hydrogen production reaction and maintain a constant volume of solution within the reactor.

The gaseous stream continuously vented from the reactor will contain nitrogen, hydrogen, and carbon dioxide. Most of the carbon dioxide is to be removed via chemical absorption by monoethanolamine (MEA). The liquid in the reactor will not be removed until the end of each batch, at which point the solid and liquid components will be separated by centrifugation. The residual solid components – cellulose, hemicellulose, and lignin – will be disposed of by incineration. This is an area in which the heat generated is useful in supplying heat to another portion of the process. Several possibilities have been identified as potential waste treatment solutions.

This report presents a successful assessment of HydroGEN's designed demonstration plant. Given ease of scalability for this process, a biohydrogen production plant is expected to eventually operate profitably. Several interesting scenarios have also been laid out as anticipated areas of improvement for this novel approach to hydrogen production.

Board Number: 14

Converting Paper Sludge to Ethanol

Ben Donnalley, Leon Garcia, Daniel McIlmoyle, Ben Roberts,

Advisor: Dr. Steven Peretti, Dr. Richard Venditti

Unstable petroleum prices and a political environment that increases the need for energy independence has created a market for alternative fuel sources in the United States. The demand for liquid transportation fuel with properties similar to petroleum has created interest in biofuels. The maturity of corn ethanol technology has made ethanol the primary biofuel produced and consumed in the United States. Ethanol produced from cellulosic biomass, such as paper sludge, is likely take over the US ethanol market in the future.

Paper sludge is a byproduct of paper production. It is often land applied as a crop conditioner, but its high carbohydrate content allows for utilization of paper sludge as a feedstock for fuel ethanol production. Although no commercial scale plants are currently in operation, enough technology is in place for construction of a paper sludge to ethanol plant.

For this project, initial material balances on unit operations were performed and a large-scale ethanol production plant capable of processing two hundred tons of paper sludge per day was designed. Unit operations including mechanical separation of ash from the sludge, hydrolysis and fermentation of the carbohydrates in the sludge, and distillation to separate ethanol from the sludge were included in the process design.

Three pieces of equipment for removal of reaction-inhibiting ash from the sludge were investigated: screw press, sidehill screen, and gravity decker. Gravity decker was selected for this process design because of its high ash separation, relatively low fiber loss, and operability at large scale. Simultaneous saccharification and fermentation of carbohydrates in the sludge was chosen over separate hydrolysis and fermentation due to improved reaction kinetics and lower capital costs.

Mechanical separation experiments were performed on samples of paper sludge from a recycle mill to reduce ash content in the sludge by washing through sieves with three different mesh sizes. Compositional analysis was performed on an unmodified sample of the sludge and each of the three sludges from which ash had been removed to determine moisture, ash, lignin, and carbohydrate content. Carbohydrate content from compositional analysis on the sample sludge was unfavorable in comparison to literature data, so literature data was used for sludge composition in the process design.

Process design and simulation were performed based on process parameters found in literature. Total capital costs were determined to be \$30,766,000 and total operating costs were \$48,926,000 per year. At an ethanol selling price of \$3.98 per kilogram. The revenue generated by the ethanol produced was only \$8,106,000 per year. The process was found to be not economically viable and is not recommended for implementation. Further recommendations to reduce the operating cost include on-site cellulose production and water recycling. Also, alternate technology may be needed to reduce the energy demand of the reactor.

Acetic Acid from Coal

Kevin Coley, Sam Hodge, Corey Hutcheon, David Rhoden

Advisors: Michael Lowder, Esmeralda Luna-Ramos

The goal of this project was to determine the feasibility of converting coal into acetic acid through gasification. Coal has become much cheaper per BTU than natural gas or oil, due primarily to the hazardous environmental effects of burning it. With 930 billion short tons of coal in world reserves as of January 1, 2006, it is likely that coal will remain in broad supply as a feedstock (EIA, 2009). Illinois bituminous #6 coal was given as feedstock, due to its higher heating value, closer location, and greater carbon composition. Through gasification, the hazardous effects of burning coal can be mitigated since the sulfur compounds and carbon dioxide can be separated from the beneficial synthesis gases through the use of an acid-gas removal system. These synthesis gases have the potential to produce energy or be reacted into other specialty chemicals. The proposed plant produces approximately 4000 kg/hr acetic acid.

Research was done on the various pieces of equipment needed for gasification, cleaning, methanol reaction, and acetic acid reaction. A Texaco quench gasifier was selected due to its inexpensive quench system and the low methane content of its syngas. A water-gas shift reactor was used to manage the necessary ratio of carbon monoxide to hydrogen for the methanol and acetic acid reactors. A Rectisol AGR system was chosen due to its higher selectivity of sulfur over carbon dioxide, and a Claus process was added for converting hydrogen sulfide into elemental sulfur. The liquid phase methanol (LPMEOH™) process was chosen for its greater control over temperature, allowing the catalyst to convert more of the syngas during the methanol reaction. Finally, the acetic acid plant was modeled around the Cativa reaction process due to its quicker production rate, smaller dependence on carbon monoxide partial pressure, greater catalyst stability and lower levels of contaminants, resulting in higher product purity.

Simulations were done on the acetic acid plant to determine the amounts of methanol and carbon monoxide required to meet the 4000 kg/hr of planned production. From that, the stream data could be determined for the rest of plant, including the coal and oxygen feed flow rates. Capital costs, raw materials, utilities, labor, and maintenance were all considered when calculating the cost of the project. Analysis of this plant showed that the process is not feasible at the current size and production level. The process costs more per year than the acetic acid and recovered sulfur could be sold for. The net present value of the project plant of a 20 year lifespan would be a loss of approximately \$1.66 billion. Even after the initial investment, the costs of feeding and operating the plant were much higher than the revenue being generated. The feasibility of the plant is even worse when considering the carbon dioxide tax being discussed in congress. When implemented, carbon dioxide emissions will yield an additional cost to the process, leading to a greater loss of money if invested.

Considering the costs of purchasing and operating the gasifier and AGR, an alternative was considered where methanol and carbon monoxide was purchased to be fed into the acetic acid plant by itself in order to produce the 4000 kg/hr of acetic acid. The alternative plant was determined to be more feasible than the previous, but still resulted in negative profits. The net present value of the acetic acid plant with a 20 year lifespan would be a loss of approximately \$96.7 million. Both the project and the smaller scale alternative are not feasible as neither was determined to yield a positive profit over their 20 year life spans. The results show that study of another product may be beneficial.

Ammonia Mitigation Technologies

Ryan Abernathy, Timothy Conaghan, Christian Estes, Jeffery Preece

Advisor: Jason Crump

This report analyzes five methods of ammonia removal from fly ash, a byproduct of coal-fired power plants. Ammonia in fly ash is caused by ammonia injection which is used to mitigate SO₃. Progress Energy's Asheville Plant currently utilizes ammonia injection for SO₃ control on its two coal fired units. Both units currently dispose of their ash by wet sluicing to ash ponds, but the units may be converted to dry fly ash systems in the future.

A wet ammonia removal process created by Paques uses a newly discovered bacterium, *Candidatus K. Stuttgartiensis*, to convert ammonium and ammonia into nitrogen gas. This process leads to a 95% reduction in ammonia; however, the bacteria's slow growth rate requires washout prevention methods and lengthy start up times.

Three dry processes that were analyzed are the Humid Air, Separation Technologies, and the PMI Ash Technologies process. The Humid Air process is designed to treat dry fly ash in storage silos. This process requires a large amount of time to treat relatively low amounts of ash and results in a 70% removal of ammonia from fly ash. Separation Technologies' ammonia removal process utilizes a pH shift to liberate ammonia from fly ash. This process is currently used at three coal-fired power plants in the U.S. and removes 97+% of ammonia in the fly ash. PMI Ash Technologies, LLC (PMI) patented Carbon Burn-Out (CBO) process combusts unburned carbon in fly ash and decomposes ammonia in the fly ash to nitrogen and water. This process has been used at South Carolina Electric and Gas's Wateree Station since 1999 and has an average ammonia reduction of 94 to 98%.

The wet/dry ammonia removal process is the Headwaters Process, which was specifically developed to mitigate increased ammonia levels due to ammonia injection for SO₃ control. The five processes were evaluated based on three criteria: cost, technology readiness level, and risk. Anammox is not recommended as a potential process due to the low readiness level. The Headwaters process is recommended because of its proven ability to mitigate ammonia and the low cost associated with its implementation. The Humid Air process is not recommended because the process lacks development and implementation at full-scale. The ST ammonia mitigation process is recommended as a viable solution to mitigate ammonia at Asheville Unit 2. The PMI CBO technology is also recommended should the plant decide it is economically feasible to install a process that removes ammonia from fly ash, increases feedwater heat rates, and produces a marketable product.

Atomic Layer Deposition Reactor

Christopher Hanson, Hisako Kurebayashi, Kristy Layton, Kevin Nance

Advisors: Dr. Greg Parsons

Atomic layer deposition (ALD) is a process which enables layer-by-layer growth of metal and metal oxide films on surfaces. Initially studied in the 1960s and 70s, ALD thin film processing is now traditionally applied within the semiconductor industry and is responsible for many of the latest advances in microelectronics manufacturing. It has also been discovered that ALD processing can be used to tune substrate surface energy on a number of different materials. Specifically, the behavior of a surface has been found to be directly related to film thickness, which can be controlled on an atomic scale with ALD processing.

ALD is most commonly used within the microelectronic device industry as a method to treat silicon, a highly uniform planar (2D) substrate. Alditri Technologies, Inc., an independent research company associated with Dr. Parsons' group in the Department of Chemical and Biomolecular Engineering at NC State University, has been studying the effects of ALD on novel substrates. In fact, Alditri has recently investigated more complex (3D) substrates such as textile materials. Researchers have demonstrated that ALD processing is possible on textiles; however, the process is much more technically challenging as compared to traditional substrates such as silicon. Consequently, no commercial scale ALD reactors exist for treating these complex substrates. Current bench-scale reactors used to process textiles do not provide a clear pathway for scale-up.

The primary goal of this project was to design and build a bench-scale ALD reactor optimized for the treatment of textile and other fiber-based substrates that can be feasibly scaled-up. The success of the design will be measured on its ability to ALD process 3 grams of nonwoven polypropylene with results similar to the current smaller scale reactors.

To date, the design for the reactor was finalized, built and started up. Three main experiments were conducted for the purposes of calibrating the carrier gas flow rate, optimizing system parameters for silicon substrates, and optimizing system parameters for 3 grams of nonwoven polypropylene, respectively. The carrier gas flow rate experiment yielded a linear relationship between the carrier gas flow rate and the setting on the carrier gas metering valve. The silicon substrate optimization experiment revealed that flow conditions within the reactor are ideal for ALD processing with minor variations in growth rates with respect to location within the reaction chamber. The polypropylene substrate experiment showed that treatment of 3 gram samples of polypropylene per batch is possible; however, ALD growth rates were not achieved. It is believed that with further optimization experiments the reactor will yield ALD growth rates while processing 3 grams of polypropylene.

This report demonstrates the feasibility of scaling up an ALD system designed for processing textile substrates.

Board Number: 18

**Design and Engineering of Microbial Gas-Phase Carbon Absorbers
for Power or Cement Plant CO_x Emissions**

Christopher Kwiatkowski, Daniel Peele

Advisors: Dr. Michael Flickinger, Dr. J. Gosse

The goal of this project was to design a process that recycles CO_x emissions from a Portland cement factory into transportable liquid fuel products, using microbial organisms embedded in a nanoporous polymer membrane. Thus, the project targeted two key areas of interest: providing a way to recycle CO_x emissions as well as providing an alternative to fossil fuels. The proposed method was compared to other current and potential routes used to provide either one or both of these functions, including chemical methods, cement manufacturing alternatives, carbon sequestration, corn and cellulosic ethanol production, and various biological routes. A cement plant was chosen as a source of CO_x due to the relatively high outputs and the smaller scale when compared to other high emission industries.

The completed design for the microbial carbon absorber implements a *Cl. ljungdahlii* and *Rps. palustris* coating photobioreactor to capture CO and produce ethanol. An algae photobioreactor is then used to absorb the remaining CO₂. The biomass is harvested so that the algal oils may be extracted. The oils undergo a catalytic reaction with ethanol to produce biodiesel by transesterification, with the residual biomass being anaerobically digested in order to generate biogas. The separation techniques employed throughout the process make use of the ready availability of CO₂ from the cement plant. Ethanol is recovered by CO₂ gas stripping and algal oils are extracted using supercritical CO₂, eliminating requirements of additional solvents.

Using laboratory rate data for a latex-immobilized coating of *Cl. ljungdahlii*, the required size and costs of a bacteria coating reactor were estimated. Additional data reported in literature was obtained for the estimation of capital and operating cost for the remainder of the proposed process. A capital cost for the process was estimated to be \$1.5 billion with an annual operating cost of \$860 million and annual revenue of \$280 million. However, the capital cost of the cement plant itself is only \$450 million, making the proposed process economically unfeasible.

However, these results were based on data from an unoptimized laboratory scale model. By factoring in relatively small increases in the activity and productivity of the microorganisms, the process economics are dramatically improved, with a capital cost of \$99 million, annual operating cost of \$22 million, and annual revenue of \$200 million. A stepwise process implementation was proposed consisting of three development stages. Using this approach decreases the financial risk associated with commercializing the technology. These improvements in the microorganisms' reactivity would make the process economically attractive without the need for government regulations or subsidies and should therefore be the targeted areas for future research.

Board Number: 19

Cholera Surveillance of Drinking Water in the Developing World

Courtney Fox, Stephen Morton, Sindhu Sevala

Advisors: Dr. Stephen Walsh

Cholera is a severe bacterial infection caused by the bacterium, *Vibrio cholerae*. Contraction of this pathogen causes such physical markers as exhaustive watery diarrhea and severe vomiting. This characteristic of cholera renders many infected patients to be particularly susceptible to rapid dehydration and electrolyte imbalance, which, depending on the severity of the case, can be fatal within hours. Cholera is contracted most prevalently through poor drinking sources, usually due to a lack of infrastructure to sustain clean drinking water supplies or proper sanitation. Despite the continued advancement of society in general, cholera continues to pose serious issues for the developing world, where increases of 24% in number of cholera cases and 27.5% in cholera-related fatalities have been reported in the most recent 5-year period. For this purpose, early detection methods are in high demand to prevent cholera outbreaks, which are seasonal in many parts of Africa, Asia, and South America.

We present a technology, CholerID, which will facilitate rapid analysis of cholera contamination in water supplies prior to consumption. Utilizing a diagnostic immunoassay, specifically a silver-enhanced nanoparticle-labeled methodology for detection of the cholera pathogen, we will provide a simple, low-cost, and effective way of detecting cholera in dilute quantities, with limits of detection approaching that which will negatively impact an individual's health upon consumption. CholerID will be completely self-contained and available for immediate use upon production and distribution. This device is currently being produced in the laboratory, but the technology is scalable.

Our company is a for-profit enterprise that will gain prominence in the global health community by networking at local and national conferences such as the National Academy of Engineering Grand Challenges Summit as well as the World Health Care Congress Affordable Health Innovation Exhibit. We have garnered financial support for our product development through a number of different sources, including BMEidea, an N.C. State Undergraduate Research award, a Parks scholarship GRASP award, and start-up funds from the EEP program. We plan to develop rapport within the global health community through conferences and trade shows to subsequently seek out strategic partnerships with organizations, such as NGOs, Gates, Diagnostics for all, and FIND, that share our vision in facilitating global health humanitarian efforts. We are currently seeking \$5 million in a combination of venture capital and angel investments to facilitate prototype development and FDA regulatory approval for year 1 and 2, as well as support the scale-up of manufacturing of CholerID chips. Following initial device implementation, we are also seeking \$3 million to fund expansion in all global markets and further technological advancements. Based on a 10-year market analysis, we expect a 5X ROI, with an invaluable social ROI in the form of countless lives saved.

For initial prototyping and proof-of-concept, we are investigating a model antibody-substrate system (goat anti-mouse IgG with mouse IgG as our substrate) to optimize our technology. This is to minimize costs in development of our technology as research involving the target cholera pathogen incurs additional costs in procurement and safe handling procedures. Once optimized, the fundamental detection scheme for our technology can serve as a platform for expansion in diagnostics of a wide range of health- and environmental- related issues, thereby supporting a number of critical current global humanitarian efforts.

Board Number: 20

Liquid Body Armor

Emily Lattimer, Brendon Stout, Peter Venema, Amanda Vorenkamp

Advisors: Dr. Michael Dickey, Dr. Saad Khan

Modern day body armor consists of 20 to 35 layers of a strong woven fabric, Kevlar®. The suits are inflexible and can be extremely cumbersome. Because of this, armor typically can only be used for the torso and helmet, leaving the extremities vulnerable. Military personnel, police officers, and prison guards all encounter stabbings and shootings capable of penetrating many types of armor. The goal for future body armor is to create a material that is light, flexible, and capable of protecting the user without compromising mobility.

The focus of this project is the development of a bench scale process to create silica based shear thickening fluid (STF) for the purpose of application to Kevlar®. The goal is to produce an STF and evaluate its effect on Kevlar® armor.

Research suggests that the application of an STF improves the protection offered by Kevlar®. With greater protection per layer of fabric, fewer layers will be required, resulting in greater flexibility and reduced weight. With increased mobility, the application of body armor to the extremities is a feasible goal. The experiments carried out in this project strongly support the assertion that STF improves the Kevlar®'s performance.

This project was successful in its goal to evaluate and develop a bench scale process to create silica based STF, including functionalizing the silica nanoparticles. The process included the application of STF to Kevlar® fabric. The bench scale system was designed as a basis for scaled up processes to work from. Further research will be necessary to determine the specifications necessary for a large scale process.

In order to test the final product of the process, the STF treated Kevlar® weave was analyzed using ballistics experiments. Protection was evaluated using both bullets of varying calibers and a drop tower for repeatable stab tests. More extensive trials are necessary to make firm conclusions regarding the effectiveness of STF, but all experiments indicated increased performance under the experimental conditions tested.

This report details the technical aspects of the STF, the experimental findings in developing the process, and the ballistic results.

Board Number: 21

Remotely Operated Biological Warfare Agent Detector

Michael Brown, Michael Farrow, Matthew Gebbie, Alexander Majeska

Advisor: Dr. Orlin Velev

The Bioseek 2500 will be an innovative microfluidic biosensor that will autonomously, quickly, and accurately sample a large area for the environmental presence of anthrax. Since the 2001 anthrax bioterrorism event in which anthrax was mailed to United States government offices and news agencies, improvements have been sought in the field of anthrax detection. The Bioseek 2500 aims to fill the current void in fast, accurate, and simple real-world anthrax detection.

Microfluidic principles were utilized to design a miniaturized device that minimizes material requirements. The design of this device features a disposable cartridge, which will allow expensive components like pumps to be reused, that will contain multiple sampling sites, antibodies, and the other reagents required for detection. A GPS device will be used to track the collection location for each of the sampling sites, and the sites will be automatically analyzed for positive results at the conclusion of sample collection. In the event that a positive signal is yielded, the GPS tracking will allow a smaller contaminated area to be distinguished from the overall sampled area. This GPS tracking system is essential, because we have determined that the current state of microfluidic biosensor technology does not allow for the realistic design of a continuously-operating anthrax sensor that will meet this project's defined goals.

The Bioseek 2500 will be tailored for military field-use but could also be beneficial for homeland security applications. This device is designed to be mounted on a GPS-guided remotely operated vehicle and will collect samples along a predetermined route. The use of a remotely operated vehicle will greatly minimize personnel exposure to anthrax in the event of an anthrax biological warfare attack and will allow accurate tracking of sampled locations. In the event that a group of people is already exposed to an area that tests positive for anthrax, the greatly shortened detection window of this device should allow exposed persons to receive timely, life-saving medical attention. Although the Bioseek 2500 is designed to detect anthrax, this device can be easily modified for the detection of other biological threats.

We have successfully selected technologies for use in our device design, and the major selected technologies are: an aerosol to hydrosol system for sample collection and processing, a micro-pump for fluid transport within device, and a gold nanoparticle-based, silver-enhanced immunoassay for anthrax detection. Additionally, information has been compiled regarding: the potential product market and demand, existing competitors, and the fundamental scientific principles of microfluidics. Given rough material cost estimates, the price for each unit of Bioseek 2500 is estimated to be approximately \$5000, but a more rigorous economic analysis needs to be performed before a more exact unit cost can be defined.

Board Number: 22

Decontamination Packet Design

Leigh-Ann Bender, Elizabeth Butler, Raleigh Davis, Lara Jazmin, Mariah Woodroof

Advisors: Dr. Behnam Pourdeyhimi

There are a variety of applications and markets which can benefit from research, development, and design in nonwoven composite materials. By incorporating different additives into nonwovens, one can manipulate their material properties. The focus of this project is to incorporate adsorbent materials into a nonwoven base in order to create a superadsorbent composite material.

Applications of highly adsorbent nonwoven composites are numerous and include use in filters and decontamination systems. This project focuses on the design of a personal and disposable chemical decontamination wipe which can be applied by the user to the skin in combat situations in order to protect from exposure to chemical warfare agents.

To create such a wipe, a variety of materials were considered. The proposed wipe design consists of a composite of four material components/layers. The first layer consists of an impermeable (to aqueous solutions) barrier film to be made from a polyolefin. The second and fourth layers are absorbent nonwoven materials, with one layer made of cotton and the other a cotton/PET blend. The purpose of these nonwovens is to absorb the chemical contamination and deliver it to adsorbent filler entrapped between the nonwoven layers, which acts as a filter. In addition, the nonwovens give the wipe structural strength and integrity, hold the adsorbents in place, and provide comfort to the user's skin. The third layer consists of granular activated carbon, an adsorbate, which is notable for its ultra high surface area-to-volume ratio, responsible for its high adsorbent properties. A pressure sensitive adhesive will be used to attach the barrier film to the first nonwoven layer.

In producing prototypes of the wipe, several textile processes were used. Nonwoven production was carried out at the Nonwovens Institute at NCSU and utilized a carding process followed by a bonding process (needlepunching). The barrier film and activated carbon materials were purchased/donated. The adhesive was applied using an ITW Dynatec hot melt adhesive unit. Final prototype composites were produced both at the Nonwovens Institute and also at ITW Dynatec's facility in Hendersonville, TN.

The starting and final product materials were experimentally tested for a variety of material properties, including mechanical strength, overall adsorptive and absorptive capacity, and surface area of the porous carbon. The highest technical priority of the project was to optimize the adsorptive capacity of the wipe, which involved incorporation of activated carbon into the composite without sacrificing the overall surface area of the carbon.

After gathering experimental data on the composite samples and calculating the economic and environmental impacts of the designs, a prototype sample and a production process were selected. The composite is to be constructed from two nonwoven layers, one layer cotton and the other a 50/50 cotton/PET blend, which are then needlepunched together, entrapping activated carbon. Initial estimates show this process can produce approximately 30 million units of superior decontamination product with profits greater than \$7 million per year. The Decon(Wolf)Pack team recommends adopting this product and process for large scale chemical decontamination wipe production.