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Developing a Strategy for Integrating Green Chemistry in Thailand

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Project Number: JRK C061

DEVELOPING A STRATEGY FOR INTEGRATING GREEN CHEMISTRY IN THAILAND

An Interactive Qualifying Project Report

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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Date: March 2, 2006

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EXECUTIVE SUMMARY

Recent industrialization and growth of the chemical industry in Thailand has led to severe environmental degradation (Iwami, 2001). Each year, 1.7 million tons of hazardous waste are generated in Thailand and 78% of this waste comes from industry (NRC-EHWM, 2005). This figure may be even higher since Thailand lacks a systematic way to inventory chemicals and hazardous waste (Kamolsiripichaiporn, 2006).

Motivated by the need for long-term solutions to this growing problem of hazardous waste and toxic chemicals use, a new strategy to solve this problem has gained widespread recognition. It relies on a fundamental redesign of chemical reactions and processes for every type of application, and marks a conceptual revolution in the discipline of chemistry (Hutchison & Doxee, 2004). This approach is called "green chemistry." As defined by Dr. Paul Anastas and Dr. John Warner (1998), green chemistry is "the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products" (p. 11).

The goal of this project was to make recommendations for establishing a successful green chemistry network in Thailand and to design a workshop that would initiate this process. To achieve our project goal, we established three main research objectives:

1. To determine common elements of successful networks that incorporate government, industry, and academia to promote environmental change
2. To identify and recommend phases necessary in establishing a green chemistry network in Thailand
3. To design a workshop which will contribute to the first phase of creating a green chemistry network in Thailand

In order to complete these objectives, we gathered information via interviews and archival research. We interviewed founders of current successful environmentally conscious networks to gain an understanding of the factors that have contributed to their success. Additionally, we interviewed chemistry professors at Chulalongkorn University to gain understanding of student and faculty interest in and knowledge of green chemistry. We also interviewed green chemistry experts in order to gain further knowledge of successful green chemistry workshops. Finally, archival research was conducted on environmentally conscious networks, as well as on logistical details to designing a successful workshop.

Key Elements of Successful Networks

We found six key elements common to existing successful networks. They were:

1. Communication
2. Education
3. Academia Involvement
4. Industrial Involvement
5. Government Involvement
6. Core Group of Leader

These elements were common themes between the successful networks we analyzed.

1. *Communication between academia, industries, and government is a key element of successful networks.*

In order to achieve their missions and goals of increasing communication, networks provide activities and conferences for their members. The Greening of Industry Network (2006) "provides an *open forum* for creative debate to engage researchers, business, workers, government, consumers and other actors in developing a shared understanding of the changes required for creating a more sustainable future." The Green Chemistry Institute (2006) "hosts *conferences* and coordinates efforts with an international network of green chemistry advocates" to increase communication about green chemistry on a global scale in order to work towards their mission of increasing green chemistry knowledge and use.

2. *Successful networks use education as a way to teach the public and network members about the ideals they represent*

The Green Chemistry Institute (2006) supplies information to "increase awareness and understanding of Green Chemistry principles, alternatives, practices, and their benefits within traditional educational institutions, and among practicing chemists and other scientists." Six out of the seven networks we researched used publications or their own journal to educate others about the recent activities of the network. For example, the Greening of Industry Network (2006) uses publication series in order to "extend the reach of the research and dialogue of our convenings."

3. *Networks incorporate the involvement of academia as a way to further research of the ideals of the network*

Dr. Kurt Fischer (2006) stated the importance of incorporating universities in the network as: "There job is to connect to the world. Sometimes current research is seen as irrelevant to university teachings, the network is trying to remedy this by incorporating them in it." About half of the members of the Greening of Industry Network are from universities which include faculty and graduate students (Fischer, 2006).

One of the primary objectives of the Green Chemistry Institute (2006) is "to advance research in Green Chemistry by promoting funding, increasing opportunities, and developing information on the benefits of green chemistry." Incorporating academia into the network helps to advance research on green chemistry and to develop further information on the societal benefits of green chemistry. GCI (2006) specifically includes members from academia on their advisory board.

4. *Including industries in the network serves as a way to implement the ideals presented by the network in industrial processes.*

Although networks incorporate involvement from many different sectors, industries typically can have the largest impact in making changes to their processes because they are currently the main producers of waste. Dr. Kurt Fischer (2006) from the Greening of Industry Network stated, "Industrial developments are the biggest influences on environmental change these days." Each of the networks we researched had strong industrial membership. . The Green Chemistry Institute (2006) includes industries as a way to increase "industrial implementation of green chemistry."

5. *Government support and involvement is used to motivate further research and practices of the network ideals.*

Many networks are sponsored by governments, or include policy makers as an influential sector of their organization. The Green Chemistry Institute (2006) was formed through the

United States Environmental Protection Agency. About 20 % of the members of the Greening of Industry Network are governmental in nature (Fischer, 2006).

6. *A core group of leaders maintains organization and manages communication of the network*

Each of the networks we researched had some form of a core group of leaders. The formal name of these leaders varies between networks. Common names included: “steering committee”, “governing board”, “board of directors”, or “management team.” Regardless of the name, each of these boards serves the same purpose, which is to maintain the network and keep all members informed of its activities.

Dr. Kurt Fischer (2006) stated that he started the Greening of Industry Network by “finding a small core of people with mutual interests who were willing to work on it because it was a part of their life goals or jobs.” Dr. Paul Anastas (2006) stated that it was important to bring the people interested together in order to raise public awareness.

Phases in Establishing a Green Chemistry Network

We used our findings of the key elements listed above to recommended four phases of action necessary to establish a green chemistry network in Thailand. In this context, we defined a network as: an organized infrastructure for collaboration and sharing of ideas and technologies among educational institutions, government and industry for the purpose of facilitating the use of environmentally benign industrial processes.

We recommended four phases of action designed especially for use at Chulalongkorn University in Thailand. We also recommended specific actions that can be taken within each phase. The four phases are:

1) Expand interest in green chemistry
2) Form a core group of researchers
3) Reach out to industry
4) Gain support from government

Below we provide an in depth description of our recommended phases.

Recommendation: Phase 1 should be to expand interest in green chemistry.

In phase 1, we recommended expanding interest in green chemistry by holding workshops for students and educators. An important part of holding a workshop to advance interest in green chemistry is to consider what will occur following the workshop. This involves keeping the subsequent phases in mind, but also the general goal of the green chemistry network we recommend. Many of the green chemistry experts we interviewed emphasized keeping the overall goal in mind. Dr. Ed Brush (2006) stressed this idea by saying, “You need a plan or strategy. I think that a seminar or seminar series is a great idea, but what will be the follow up? You still need faculty involvement to keep the momentum going.”

Recommendation: Phase 2 should be to create a core group of green chemistry researchers to act as the board of directors for the network

Many networks were started with a core group of researchers. They had an initial small group of people who spent a large amount of effort expanding the network and increasing others’ knowledge of the purpose of the network. This core group of researchers can form a board of directors, or advisory board, for the network and can serve to run the network and to maintain the communication throughout the sectors involved in the network.

We recommended this as the second phase because increased interest in green chemistry is a necessary prerequisite. The completion of this phase relies on the existence of one or more persons who serve to lead this green chemistry movement in Thailand. In this phase, we also suggest that the core group of leaders consist of individuals with a diverse set of personal accomplishments to add credibility to the network.

Recommendation: In phase 3, the network should involve industries through outreach programs

In phase 3, we recommended that the core group of researchers created from Phase 2, promote the network to others, and specifically focus on gaining participation from industry. This is important to our proposed network because green chemistry is directly applicable to the chemical reactions and processes used in many industries (Warner, 2006). Therefore, a tremendous potential for lessening the environmental impact of these processes exists. According to Dr. Julie Haack (2006), industries are unlikely to be interested unless green chemistry will save them money. As a result, we suggested that the core group of researchers approach individual companies and explain both the economic and social benefits of green chemistry.

Next, we recommend a general conference be held at which these same companies demonstrate current green chemistry processes in use around the globe, highlighting how its use has benefited companies and society. At this conference, the core group of green chemistry researchers should present their ideas and goals for the future of forming a green chemistry network in Thailand. Ideally, this process will aid in generating industrial interest in green chemistry.

Recommendation: Phase 4 should be to develop government recognition and communication

Another way to motivate industries to join the network is to incorporate government involvement. Reasons for including the government in the network are to increase funding, grants, and award opportunities (Haack, 2006). Also, the government creates policy and has the ability to place stronger control on importation and tracking of chemicals in Thailand.

Government awards are an effective way to motivate industries and researchers to use or study green chemistry. Paul Anastas (2006) specifically stated that one of the main steps in creating a successful green chemistry network is to "establish a national award to recognize accomplishments in green chemistry for industries." Anastas (2006) has created an award like this in many countries with the spreading of the Green Chemistry Institute.

As explained above there are four conceptual phases recommended to create a green chemistry network in Thailand. To initiate the process of making the first conceptual phase of expanding interest in green chemistry into a tangible event, we suggest a one day long undergraduate level workshop.

Our recommended workshop

We recommended holding a one day long workshop for undergraduate students as an appropriate first step for starting a green chemistry network in Thailand. According to the Chulalongkorn University chemistry professors we interviewed, most undergraduate students currently have limited or no understanding of green chemistry. Keeping the workshop length to one day will increase the likelihood for student participation because less time commitment is required of them. Professor Julie Haack (2006) from the University of Oregon agreed that it would be impractical to expect university students to commit to a workshop longer than one day because green chemistry is unfamiliar to many of them. In an interview she stated: "It will be very difficult to get undergraduate students to give up a weekend or a lot of free time."

Another important aspect to increase student participation in a green chemistry workshop was to design the workshop such that students do not perceive it as simply extra "work" for them to do (Warner, 2006). This potential issue is another reason to keep the time commitment short.

We found undergraduate students to be the best age group for an initial workshop to begin the process of creating a green chemistry network in Thailand. To completely comprehend green chemistry theory and practice requires some prior experience with general chemistry and preferably with organic chemistry. A second reason we recommended the undergraduate age group is that soon after the workshop, most students will be either entering the workforce, or continuing on to graduate school. This is important because our recommendation for a network requires participation from industry, university, and government.

Workshop Logistics

We also provided recommendations for the logistics of the one day undergraduate workshop described above. Our recommendations were based on the following findings:

1. The past workshops held by educators have all had the common goal of increasing knowledge of a particular subject.
2. Interactive laboratories are the best way to maintain audience interest during workshops.
3. Small attendance workshops are more conducive to in-depth learning
4. There are numerous ways to fund our proposed workshop.
5. Our recommended workshop can be successfully run on a budget of 6000 US dollars.
6. Many methods of publicity have been successful for past workshops at Chulalongkorn University.
7. Students are more likely to attend a workshop or seminar if the professor who suggested it to them shows personal interest.

From these findings, we made the following five recommendations for the logistics of a one day undergraduate workshop:

a. Purpose: To generate interest among undergraduate students in green chemistry by providing educational lectures and interactive laboratories.
b. The workshop should be comprised of a small lecture portion and a large laboratory component.
c. The number of attendees for our proposed workshop should be 20 to 30 students.
d. Our sponsor should apply for the Green Chemistry Institute's Developing/Emerging Nation's Grant and to any other funding sources available
e. The logo, brochure, flyer, and website we have designed should be used to advertise the workshop.

In addition to providing in depth example of the first action, we also gave information on different workshop lengths of one, two, and three days and different age categories of primary, secondary and undergraduate. These options can be applied to our recommendations of the one day workshop for undergraduates. We also provided sample green chemistry laboratories for all three age categories that can be used in future workshops.

When implemented within the next year, our workshop will initiate the first phase of leading towards the establishment of a green chemistry network in Thailand. Use of a green chemistry network can benefit the environment and economy in Thailand. Increasing and facilitating communication between industries, educational institutions, and the government will reduce the problems with the tracking of chemicals in Thailand. A network would also be beneficial to students who wish to do research and will be able to work with a company while still in undergraduate school through outreach programs.

Further Recommendations

In addition to the recommendations summarized above, we also recommend future projects that build on the achievements of this project. These recommendations take into consideration other work that can be accomplished in the area of green chemistry in Thailand. These recommendations are:

1. Green chemistry should be implemented at the undergraduate level at Chulalongkorn University. Given the professor interest we found, this recommendation can take place in two ways: green chemistry can be offered as an elective course or implemented in the existing laboratory and curriculum. A combination of both of these would be the best future option for increasing the education of undergraduate students at Chulalongkorn University.
2. We recommend that our sponsor collaborate with other existing environmental networks because we found numerous thriving networks that promote environmental change. To start a new network while forming an alliance with these already successful networks will provide our sponsor with existing ideas that have succeeded, and establish contacts in government, education, and industry.
3. We recommend that our sponsor improves her relationship with the Green Chemistry Institute to use available resources. The Green Chemistry Institute has numerous experts and network advocates that can provide resources to our sponsor.
4. The improvement of Chulalongkorn University's graduate level green chemistry research. This will strengthen our proposed network through research and development of green chemistry in the laboratory. Also, to create proficient green chemistry experts, more students need higher level experience with green chemistry.

Summary

By completing our goal, we have produced plans for a workshop that our sponsor can hold within the next year, and a list of phases of actions that can be followed after the workshop is completed. Our proposed workshop and recommended phases of action will increase the use of green chemistry in Thailand and result in the establishment of a green chemistry network. In addition, we recommended the long term goals of implementing green chemistry into Chulalongkorn University's undergraduate program, collaborating with existing networks that promote environmental change, strengthening alliances with the Green Chemistry Institute, and improving Chulalongkorn University's graduate program.

A green chemistry network will benefit Thailand through the utilization of collaboration between industry, academia and government. This can improve the chemical industry's traditional methods of production and reduce the pollution generated from these methods. A green chemistry network can potentially advance society to create a better environment while still providing economic benefits to industry in Thailand.

The chemical industry produces many benefits to society; however, often harmful chemicals are used or produced in the process of manufacturing these beneficial products. Green chemistry provides a framework to break this cycle through strategic redesign of current traditional chemical processes. This enables chemists to manufacture these useful products without using or generating toxic substances. In turn, the economic, social and environmental benefits of green chemistry will improve the standard of living, and assist the continuing development of Thailand.

ABSTRACT

This project explored the development of recommendations for a strategy which will integrate green chemistry into Thailand. We provided recommendations for the phases our sponsor has to achieve, as well as specific actions she may take to successfully develop a green chemistry network in Thailand. In order to continue the first phase, we provided recommendations for the logistics of a workshop for undergraduate level students.

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TABLE OF CONTENTS

List of Tables

List of Figures

1. INTRODUCTION

Chemical interactions are present in every aspect of our lives from the food we eat to the products we use. The chemical industry is growing quickly with Asia pioneering its development. In East Asian, growth index was 11% in 2004, compared with a global average growth of 3.3% (Tyagarajan, 2004). According to the OECD (2001), based on the 1995 production levels, the chemical industry is projected to grow 85% by 2020 (OECD, 2001). While the chemical industry has provided many benefits to our society, many of the chemicals used and byproducts produced have harmful effects on the environment and humanity.

Often, chemists create reactions to make desired products only considering the economic benefits (Collins, 2001). With a growing public awareness that some chemicals are harmful to human health, chemists are beginning to understand that their actions can significantly impact other people and their surroundings. "Green chemistry" has the potential to change the traditional industrial practices without compromising economic benefits.

Green chemistry is a particular means of applying environment-friendly chemical practices in industry and research. Green chemistry has been proposed as a strategy for pollution and hazardous waste prevention in which chemical processes are redesigned to be environmentally benign and produce less waste (Anastas & Warner, 1998). Dr. Paul Anastas and Dr. John Warner (1998) define green chemistry as "the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products" (p. 11). It is one solution to help reduce waste production and the use of toxic materials. Green chemistry can also help mitigate the costs that are associated with proper waste disposal, and increase overall production efficiency (Anastas & Warner, 1998).

One way to promote the integration of green chemistry into a country's industrial infrastructure is by creating a network that increases communication between industry, academia, researchers and government (Anastas, 2006). We have defined a network as: an organized infrastructure for collaboration and sharing of ideas and technologies among educational institutions, government, and industry for the purpose of facilitating the use of environmentally benign industrial processes. Green chemistry networks have been developed successfully in many parts of the world such as the United States, Japan, and the United Kingdom. Examples of these networks include the Green Chemistry Institute (GCI, 2006) in the

United States, the Green Chemistry Network (GCN, 2006) in the United Kingdom, and the Greening of Industry Network (GIN) which has divisions in the United States, Europe, and Asia.

Green chemistry is still an incipient idea in Thailand. If incorporated into current industrial chemical processes, green chemistry can play a part in helping to reduce the estimated 1.7 million tons of hazardous waste that are produced annually by industries in Thailand (NRC-EHWM, 2005). Currently, a formal green chemistry network does not exist in Thailand, yet there is interest amongst chemistry professors at Chulalongkorn University in Bangkok in creating one. The lack of resources and time for intensive research on how to begin a network has been a strong barrier to planning and implementing a green chemistry network in Thailand. This project seeks to help address these issues.

The goal of this project was to recommend a strategy for establishing a successful green chemistry network in Thailand and to design a workshop that would initiate this process. Our efforts to achieve this goal included researching current networks that promote environmental change and understanding what makes them successful today. In order to recommend phases of creating a green chemistry network in Thailand, we relied on the advice of network founders and green chemistry experts. The first phase includes workshops to educate university students and professors about green chemistry. To help ensure the success of this network, we proposed detailed recommendations for this workshop. By developing ideas for a workshop that could be given to students, we provided a strong starting point for a future green chemistry network in Thailand. Green chemistry networks provide a means for different areas of research to combine their ideas and encourage the use and research of green chemistry to others. Through communications between industries, government, research, and universities, industrial practices can be made to have less harmful impacts on human health and the environment.

2. BACKGROUND

In the past, most people were unaware of the harmful affects that many chemicals pose to the environment and human health. In recent years, concern has grown surrounding this issue. Legislation has been put in place in many countries in order to manage chemical hazards to humans and the environment .However, there is little legislation intended to limit the creation of toxic substances, or to prevent pollution from being generated. Over the past 15 years, a new framework has been developed which can provide long term solutions to the many problems associated with hazardous chemicals and waste. This framework is termed green chemistry. This chapter develops the broad context of our project and motivates the need for a strategy of increasing green chemistry use in Thailand.

2.1. Impacts of the Chemical Industry

Seven percent of the world's global income is generated from the chemical industry and it accounts for 9% of the total global trade, making it twice the size of the world market for telecommunications equipment and services (OECD, 2001). Also, the chemical industry in East Asia is growing fast, expanding by 11% in 2003 versus a global average growth rate of only 3.3% in that year (Tyagarajan, 2004).

Products made by use of chemical processes permeate our everyday lives. Without these products, our lives would be very different and would not include many of the highly beneficial products common today. Among the most noteworthy are pharmaceutical products. However, the process of manufacturing these products often involves the use or creation of substances which are toxic to human health and the environment.

2.1.1. Harmful Chemical Affects

Chemicals affect every aspect of our lives. Although the chemical industry has produced many benefits for humans, many of these chemicals are toxic, or are produced using toxic chemicals to human health and the environment. In the pharmaceutical industry, 4% of prescriptions produce serious side-effects and 0.1% of these effects are fatal to the patient (Eaton & Anthony, 2000). Also, over 3,000 synthetic chemicals are added to our food each year (Eaton & Anthony, 2000). As early as 1982, over 75% of our diet was processed food (Eaton &

Anthony, 2000). In addition to the everyday chemicals present in our lives, chemical disasters have raised awareness about the effects of harmful chemicals.

Use and storage of industrial toxic chemicals or waste increases the risk of major disasters. For example, a chemical explosion at a Union Carbide plant in December, 1984 in Bhopal, India. This resulted in over 3,000 deaths due to acute exposure to Methyl Isocyanides (Union Carbide Corporation, 2005). Love Canal, located in Niagara Falls, NY, was an incomplete canal used as a disposal site for chemical waste because it was owned by a chemical company (Anastas & Warner, 1998). After being sealed, the Love Canal was developed for residential use and the residents were unaware of the chemical waste site below them. They realized the situation when chemicals started discharging from the ground directly into their homes and they were forced to evacuate. A third example the Cuyahoga River, located in Ohio, which caught on fire because of extremely high pollutant saturation of the river water (Anastas & Warner, 1998).

The development of public awareness of the chemical industry started from these chemical disasters and hazardous waste build-up. This awareness grew into a concern for the environment and human health. As a way to alleviate some of the risks posed by toxic chemicals, some governments produced legislation which controlled the use and clean-up of hazardous waste.

2.1.2. Chemical Regulation

Traditionally, pollution has been dealt with after it was already produced. The practice of generating pollution and then installing smokestack scrubbers or other similar devices to reduce final emissions are known as "end of the pipe" solutions (Anastas & Warner, 1998). End-of-pipe pollution management is not 100% effective and it does nothing to alleviate the hazards to people and the environment inherent in the handling, processing, and manufacture of toxic chemicals (Anastas & Warner, 1998).

Mandating end-of-pipe pollution reduction has been done through "command and control", also known as "treatment and abatement" government legislation (Anastas & Kirchhoff, 2002, p. 686). Command and control legislation seeks to limit the spread of existing pollutants, create plans for the clean-up, dictate acceptable pollutant levels, or simply give fines to the persons responsible for the violation of emissions regulations (Anastas & Warner, 1998).

Along with command and control legislation, many countries have phased out the use of some substances known to harm humans or the environment. Among these are DDT, carbon tetrachloride, asbestos, PCBs, and tetraethyl lead (Geiser, 2001). Although these chemical substances were useful in a wide range of applications, they were taken off the market in most countries due to their adverse effects to human and ecological health (Geiser, 2001). Government researchers discovered that in order to eliminate the many problems associated with these harmful substances they needed to change the chemicals in use.

2.1.3 Chemical Waste and Control in Thailand

In the past decade, rapid industrialization and growth of the chemical industry in Thailand has led to environmental degradation (Iwami, 2001). “The hazardous waste generated in Thailand has amounted to 1.7 million tons each year, of which 78% comes from industry” (NRC-EHWM, 2005, p.1). This makes the chemical industry the single largest producer of hazardous waste in Thailand. This figure may be even higher since Thailand lacks a systematic way to inventory chemicals and hazardous waste (Kamolsiripichaiporn, 2006).

The command and control strategy in Thailand used to manage this waste is largely ineffective at preventing chemical and other types of pollution from entering the environment (Kamolsiripichaiporn, 2006). According to the National Research Center for Environmental Hazardous and Waste Management (NRC-EHWM) (2005), this is mostly due to “lack of enforcement, infrastructure, technology, specific policies and regulations, public awareness, and human resource development” (p.1).

The risks associated with hazardous waste production and the use of toxic chemicals in industrial processes has gained widespread attention within recent decades. The people designing these processes have come to realize that they have a choice when creating them. They can choose to make the process more environmental-friendly, or they can find the easiest and fastest route. In the past fifteen years an emerging way of looking at chemistry has gained international recognition. It marks a change at the fundamental level in the way chemists are designing reactions and processes for every type of application. The approach is called “green chemistry” and is motivated by the need for long-term solutions to the growing problems of industrial waste and chemical pollution.

2.2. Green Chemistry

Green chemistry is a framework that applies a set of guiding principles to chemical reactions (Anastas & Warner, 1998). It is pollution prevention at the earliest step: the molecular reaction (American Chemical Society, 2004). If researched correctly, a green chemistry reaction can take the place of a current industrial process and can produce economical, societal, and environmental benefits.

Many researchers are interested in this innovative approach because it can help to sustain the environment instead of damaging it (Hutchinson & Doxee, 2004). Green chemistry has gained widespread attention and is practiced in many different countries including Australia, the United States, the United Kingdom, Canada, Japan, and the Netherlands (American Chemical Society, 2004). Despite this growing movement of green chemistry, it is not integrated as a global practice. People in many countries, including Thailand, are still largely unaware of the benefits of using green chemistry.

2.2.1. What is it?

The idea of "green chemistry" was developed by Dr. Paul Anastas of the United States Environmental Protection Agency (EPA) during the early 1990s as a means of working towards a sustainable environment (Lancaster, 2002). The common definition of green chemistry is "the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products" (Anastas & Warner, 1998, p. 11). From its beginning as an abstract idea about fifteen years ago, green chemistry has become a widely recognized and studied sub-discipline of chemistry (Poliakoff, Fitzpatrick, Farren, & Anastas, 2002).

There are many reasons that people have become interested in this new area of research. It is a new way to do old processes. If a reaction completely follows the twelve principles, it will be environmentally benign (Anastas & Warner, 1998). Green chemistry is adding to the general movement of concern for the environment and sustainability (Bora, U., Chaudhuri, M. K., Dehury, S. K., 2002). Also, green chemistry requires a chemist to think about the consequences different chemicals and reactions have on the environment. Hutchison and Doxsee (2004) feel that currently in the science community the idea of finding new "green" chemical processes is very appealing to researchers and many new and cleaner processes are being formed each year.

Also, green chemistry addresses chemical waste produced from everyday processes such as food, dry-cleaning, and pharmaceuticals.

Green reactions use “green agents” which are chemicals that are less harmful to the environment and society compared to traditional chemicals (Lancaster, 2002). Chemists are guided in their research by the previously mentioned set of principles, shown in Figure 2.1. These were developed by Dr. Paul Anastas and Dr. John Warner (1998). These twelve principles serve as a “roadmap” for chemists who choose to practice green chemistry (Pellerin, 2005).

Figure 2.1. The 12 Principles of Green Chemistry

1. It is better to prevent waste than to treat or clean up waste after it is formed.
2. Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment
4. Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5. The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary wherever possible and, innocuous when used.
6. Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.
7. A raw material of feedstock should be renewable rather than depleting wherever technically and economically practicable.
8. Unnecessary derivization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.
9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation of the products.
11. Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. Substances and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

From: Anastas and Warner (1998) Figure 4.1, p. 30.

Green chemistry is applicable to a myriad of different types of chemical reactions. Lancaster (2002) discusses the types of chemical reactions and processes that are currently being studied, including: catalysis (both heterogeneous and homogenous), photochemical reactions, sonochemistry, electrochemical synthesis, and the use of non-volatile organic solvents.

According to Dr. Anastas (2006), green chemistry processes can be applied as an alternate for all industrial chemical processes.

2.2.2. Green chemistry is becoming a global movement

During the last decade, interest in green chemistry has grown significantly and there is now a large effort to promote the worldwide use of green chemistry. The benefits of green chemistry, including monetary, societal, and environmental, are appealing to a large audience including governments, private industries, researchers and universities (Anastas, 2006). Through the networking of green chemistry research and development, many countries have already begun to encourage the use of green chemistry reactions in industry. Also, professors and researchers are discovering widespread applications of green chemistry in academic settings.

In 2005, the global green chemistry movement effected many different disciplines. The University of Nottingham, U.K., adopted a program titled DICE, Driving Innovation in Chemistry and Chemical Engineering, which is planning to give students training in Green Chemistry and Green Engineering (American Chemical Society Green Chemistry Institute, ACS-GCI, 2006). In Australia, the director of the Australian Green Chemistry Centre at Monash University in Melbourne was awarded for his research with the Royal Australian Chemical Institute Medal (ACS-GCI, 2006). Ethiopia had its first Green Chemistry Workshop for students, professors, and industry run by Addis Ababa University and the University of Nottingham (ACS-GCI, 2006). In June, the largest meeting of Green Chemistry leaders occurred in Washington D.C. It included “Nobel laureates, CEOs, students, bench chemists, and policy makers” (ACS-GCI, 2006). Even Wal-Mart has now incorporated green chemistry into its products with the use of polylactic acid (PLA) as its food packaging (ACS-GCI, 2006).

These are just highlights of actions taken in the past year which show the broad range of areas where green chemistry is applicable. There are numerous other examples that have been carried out since the creation of green chemistry in the early 1990s. These are examples of how green chemistry not only affects industry with development of substances like polylactic acid, but also academia with programs such as DICE being created in many universities around the globe.

An example of government recognition of green chemistry use in industries is with the United States EPA’s Presidential Green Chemistry Challenge. This program was set up to recognize companies using green chemistry methods to reduce or eliminate negative environmental impact during manufacturing and chemical processes (U.S. EPA, 2004). The award presented in the past year of 2005 recognized the pharmaceutical industry for their achievements in utilizing green chemistry to create new medicines and to find new ways to create old medicines (ACS-GCI, 2006). One example of this is with a drug named Emend® produced by Merck (U.S. EPA, June, 2005). It uses Aprepitant, which is a chemical that reduces nausea and vomiting after chemotherapy. Previously, it needed six chemical reactions that were not very economical. Now it only has three steps which are “highly atom-economical” (U.S. EPA, June, 2005).

Current use of green chemistry is not only in the industrial sector. In past years green chemistry has also become a major part of the curriculum at many universities. These include: University of Oregon, U.S., University of Massachusetts, U.S., Worcester State College, U.S., University of Leicester, U.K., Institute of Science and Technology, Spain, University of Tokyo, Japan, University of Bremen, Germany, and Murdoch University, Australia, among many others (American Chemical Institute, 2004).

Continued research and development in green chemistry approaches has unveiled its many applications and benefits. Unfortunately, Thailand’s industries, government, and universities have yet to reap the benefits of green chemistry due to a lack resources, knowledge, and infrastructure in green chemistry. Many of the researchers in the countries that use green chemistry feel that it can greatly benefit society and the environment. They are very set on increasing the use of green chemistry in their country, and in spreading it to others.

2.2.3. Current green chemistry status in Thailand

There is a large potential for green chemistry implementation in Thailand. Currently, industries are not using green chemistry practices (Tantayanon, 2006). However, some universities are beginning to become interested in the benefits green chemistry possesses, although this movement is still very small. At Chulalongkorn University, there are several very interested professors, along with a green chemistry graduate course (Tantayanon, 2006).

The implementation of green chemistry could benefit Thailand in many ways. Students at the university, along with professors, would come to understand the potential they have on affecting the environment with their research. Also, industrial implementation would greatly reduce the amount of hazardous waste currently being produced.

Although green chemistry has been developing over recent years and there are many researchers interested in it, green chemistry is far from being a universal standard. There are many stages to move through in order to integrate it into industry and education. Some of these stages include government involvement, but others also include voluntary movements to increase the use of green chemistry through collaborations on research.

2.3. Green Chemistry Networks

The current process of implementing green chemistry use in society is through voluntary associations. These associations, or networks, incorporate the involvement of industry, academia, and government in order to further the use and education of green chemistry. By incorporating these three sectors, green chemistry networks are able to promote their ideals to a large audience, and share resources and information.

In this context, a network is defined as: an organized infrastructure for collaboration and sharing of ideas and technologies among educational institutions, government, and industry for the purpose of facilitating the use of environmentally benign industrial processes. The main reason the network is formed is to increase communication between these three sectors that normally do not interact. Currently, creation of networks is the primary means of introducing green chemistry in a country and integrating it into industry and education.

There are many voluntary local, national, and global organizations which seek to promote environmentally sustainable ideas and practices. Along with promoting greener or more sustainable practices in industries and universities, the establishment of networks has helped facilitate communication between professionals from research, education, business, civil society organizations, government, and others who are concerned about sustainable environmental practices (GIN, 2006).

Networks like the Greening of Industry Network and the Green Chemistry Institute share similar goals of trying to advance knowledge about environmental sustainability while increasing industrial use of environment-friendly practices. Most of these voluntary organizations hold several conferences throughout the year for those interested in changing their practices. The conferences serve as a forum for the sharing of the latest research and development in new technologies and procedures which reduce toxic waste generated or released into the environment (Kamolsiripichaiporn, 2006).

Efforts to improve environmental conditions through the networking of ideas are also taking place at universities. The National Research Center for Environmental and Hazardous Waste Management (NRC-EHWM) is one such academic network. It is a consortium of five universities in Thailand with the goal of strengthening academic capability, research and development, and human resource development to help solve the environmental problems plaguing Thailand (NRC-EHWM, 2006). Each of the five universities has a research center where faculty and researchers work together to solve environmental problems.

The popularity of using a network for encouraging the spread of green chemistry is growing. The Green Chemistry Institute in the United States now has sectors in over 20 countries (GCI, 2006). Many of these sectors have developed their own sub-network. Since these networks are voluntary, they mainly consist of people very interested in green chemistry. They have been able to do a great deal of work towards increasing the use of green chemistry in universities and industry. These networks have also been able to encourage their respective governments to create grants and funds for those interested in doing green chemistry research.

2.4. Chapter Summary

In the last fifteen years, green chemistry has rapidly and gained widespread recognition. Some of the world's largest corporations are using green chemistry to reduce pollution and waste, while also saving on production costs. The conventional methods of dealing with chemical pollution and waste at the "end of the pipe" are being replaced by more modern, effective, and long-term solutions like green chemistry. However, not every country is involved in the green chemistry movement. For instance, Thailand is still using traditional methods of regulating chemical processes, an approach which has had very limited success (NRC-EHWM, 2006). One step to introducing green chemistry in Thailand is to first give people an understanding of what it is and what it represents. Eventually, a voluntary green chemistry network can be created in Thailand which will help lead to safer chemical practices and a healthier environment. The next chapter describes the methods we used in order to reach our project goal and research objectives involved with introducing and developing green chemistry in Thailand.

3. METHODS

The idea of using green chemistry in a tripartite relationship of industry, academia, and government is a new idea in Thailand. The goal of this project was to make recommendations for establishing a successful green chemistry network in Thailand and to design a workshop that would initiate this process. To achieve our project goal, we established three main objectives. The first was to determine common elements of successful networks that incorporate government, industry, and academia to promote environmental change. The second was to identify and recommend phases necessary in establishing a green chemistry network in Thailand. The third objective was to design a workshop which will contribute to the first phase of creating a green chemistry network in Thailand. Information gathered under each objective was crucial to completion the next and all were stepping stones to achieving our goal. This chapter details each of these research objectives and the methods that we used in order to complete them.

These objectives were formed to provide a focus on the research we needed to perform to achieve our goal. They were specifically created in order to help us establish the elements crucial to the success of a network and to determine how to organize these elements into specific phases. In this context, we define elements as: common characteristics of existing networks which led to, or maintains their success. Each of our recommended phases incorporates one or more of the common elements of successful networks. Phases are specific to our recommendations for a network, while elements come from various existing environmentally conscious networks. In Chapters 4 and 5, we recommend that the first phase of creating a green chemistry network in Thailand be a workshop created for students. In order to take this first conceptual phase a step further to an actual event, we researched logistics and made recommendations for a green chemistry workshop for undergraduate students.

3.1. Objective 1: To determine common elements of successful networks that incorporate government, industry, and academia to promote environmental change.

This objective was created to research different networks that establish collaboration between academia, government, and industries to promote awareness of environmentally conscious topics. After we identified these networks, we researched their common characteristics or elements. These elements each form a major part of the networks.

We completed archival research on different networks' websites to learn about their goals and objectives. We used the questions in Appendix 3 as a basis for the information we searched for on their websites. These networks were chosen through network sampling. As defined by Singleton & Straits (2005, glossary) network sampling is "A sampling procedure in which respondents initially contacted in screening of probability sample are asked to identify other members of the target population who are socially linked to the respondent" In order to do this we asked network founders about other existing networks with a similar purpose. The networks we researched are listed in 3.1.

Table 3.1. Networks chosen for archival research

Network	**Location**
1. Greening of Industry Network	Global: Europe, N. America, Asia
2. Green Chemistry Network	UK: University of York
3. Green Chemistry Institute	USA, global chapters
4. Ceres	Global
5. Green and Sustainable Chemistry Network (GSCN)	Japan
6. Social Venture Network (SVN)	USA
7. National Research Center for Environmental and Hazardous Waste Management (NRC-EHWM)	Thailand

We compiled data from each of their websites then separated the information into four main categories:

- The network's goal and future vision,
- The start of the network and how it was established
- Who is involved in the network
- Main activities

After grouping the information into these categories, we analyzed these data through content analysis (Singleton & Straits, 2005). This analysis process enabled us to identify the common elements that each of these networks display. Identification of these elements led to our findings in Section 4.1 of Chapter 4.

By analyzing other networks, we were able to find the key elements that were common between each network. After finding these elements, we were able to identify what needed to be incorporated into the recommended phases of the green chemistry network we proposed. This objective helped us to reach our goal: To make recommendations of establishing a successful green chemistry network in Thailand.

3.2. Objective 2: To identify and recommend phases necessary in establishing a green chemistry network in Thailand.

To complete this research objective we interviewed founders of networks that promote environmentally conscious industrial practices and incorporate the participation of academia, government, and industry. We researched what phases successful networks moved through to become what they are today. We used this information in order to help us determine what phases apply in creating a green chemistry network in Thailand.

We interviewed three network founders to help us complete this objective:

1. Dr. Kurt Fischer
    a. Greening of Industry Network (GIN), Global
    b. Americas Coordinator of GIN
2. Dr. Paul Anastas
    a. Green Chemistry Institute (GCI), United States
    b. Director of GCI
    c. Progenitor of the term "green chemistry"
    d. Founded over 20 global chapters (Anastas, 2006)
3. Dr. Somporn Kamolsiripichaiporn
    a. National Research Center for Environmental and Hazardous Waste Management (NRC-EHWM), Thailand
    b. Director of NRC-EHWM and Asia Coordinator of GIN

We chose to interview founders of these organizations because we wanted to understand what phases they completed in creating their successful network. Our interviews with Dr. Paul Anastas and Dr. Kurt Fischer were conducted via telephone correspondence due to our location in Thailand. We were able to conduct the interview with Dr. Somporn Kamolsiripichaiporn since her office is located in Bangkok. During these interviews we inquired about the challenges faced in establishing their network, as well as the future goals of the network. The questions we asked are located in Appendix 3.

We compiled the data obtained from the interviews and separated it into three categories. The categories are:

1. The network's goal and future vision,
2. The start of the network and how it was established, and
3. Who is involved in the network

After separating each response into one of the three categories above, we analyzed the responses in each category through content analysis by looking for similarities and differences between each response (Singleton & Straits, 2005). Through analyzing Category 2 we identified different phases of creating a network. This analysis and our results can be found in Chapter 4 and Appendix 6.

We gained valuable information that was needed in order to make strong recommendations for the phases of creating a green chemistry network in Thailand. These recommendations are located in Chapter 4, Section 4.2. Through interviewing network founders we learned how each network grew from one person's vision to an international collaboration between governments, industries, and academia. Through these interviews and the archival research completed on various successful networks in the previous objective we identified what phases are applicable in Thailand. This objective enabled us to reach our goal of making recommendations for establishing a green chemistry network in Thailand. After developing the phases, we recommended an action that can be taken within the first phase of expanding interest in green chemistry. This is developed in our third research objective.

3.3. Objective 3: Design a workshop to begin the process of creating a green chemistry network in Thailand.

We recommended gaining support for a green chemistry network by holding a short workshop to introduce students to green chemistry theory and practice. This idea emerged from our research in the first two objectives and is discussed in greater detail in Chapter 5. This section focuses on our methodology for developing this workshop.

We chose to develop one workshop recommendation because we wanted to focus our efforts on developing the details required to make it successful. We split the details into subcategories which we termed workshop logistics. The logistics include: purpose, type of workshop, attendance, budget and funding, and publicity.

3.3.1. Chulalongkorn University Chemistry Professor Interviews

By interviewing Chulalongkorn University chemistry professors we completed two research tasks. One was to decipher the professors' interest and knowledge about green chemistry and the other was to help identify the logistics appropriate for a recommended workshop based on the workshops these professors had held in the past. We particularly chose to interview the chemistry professors at Chulalongkorn University because our sponsor is located within the chemistry department at this university.

We decided to interview the professors face-to-face versus over the phone for many reasons. Face-to-face interviews are more personal and it is easier to gain a level of trust during the interview (Singleton & Straits, 2005). Also, by meeting the professor in person we showed dedication and belief in our project which gained us a certain level of respect. Our inability to speak Thai meant that our questions were not always well understood by these professors. Due to this small language barrier, a face-to-face interview allowed for more detailed explanations of questions we asked to maximize professors' understanding of our questions, as well as our understanding of their responses.

We chose to interview a total of ten Chulalongkorn chemistry professors because we felt that this number gave us an accurate view of the total chemistry faculty, 75 professors, at the university. A second reason for choosing ten interviews was that as interviews were completed, we found a significant number of recurring responses to our questions. We also did not interview more professors due to time constraints of the project and non-response to our requests for an interview.

During our interviews with Chulalongkorn University chemistry professors we asked them if they had run a workshop in the past. These questions can be found in Appendix 2. If this was the case we asked them specific details about the workshops they had run. We also requested any materials from the workshops which were still available. Examples of these materials were the purpose, type of workshop, budget and funding, and publicity.

There were three steps in the Chulalongkorn University chemistry professor interviewing process. First, we created a set of interview questions. Every effort was made to design the questions to be impartial and non-leading, thus providing the most valuable information to achieving our project goal. Next, we conducted semi-structured interviews in order to discuss in more detail areas in which the professor was more knowledgeable. Dr. Supawan recommended the initial group of interviewees, then, through use of network sampling we contacted and interviewed other professors (Singleton & Straits, 2005). Before conducting the interview we assured the professor that their responses would remain anonymous. We chose to conduct anonymous interviews in order to gain a more accurate representation of the true views these professors hold of green chemistry.

The third step of this interview process incorporated compiling the interviews. This compilation can be found in Appendix 4. We compiled the interviews into four main categories:

- Feelings towards green chemistry
- Student interest in green chemistry
- Changing curriculum
- Workshop challenges

Content analysis was used to analyze the information in each of these categories based on the similarities and differences between the professors' responses (Singleton & Straits, 2005). The results of this analysis are discussed in Chapters 4 and 5.

In order to identify options for the five necessary logistics mentioned above, we first analyzed the different materials each previous workshop used. We then compared the effectiveness of purpose, type of workshop, method of funding, and publicity between the different workshops. Finally, we developed the best options for the five logistics of our recommended workshop.

We analyzed these data by reviewing what their opinions were of what was successful and unsuccessful in these workshops and compared it to our archival workshop research. Content analysis was used for this process (Singleton & Straits, 2005). After compiling the frequencies of opinions about doing one type of workshop, we compared this to the frequencies observed with our other data gathering techniques, including archival research and interviews with green chemistry experts.

3.3.2. Green Chemistry Expert Interviews

The information gathered from the green chemistry expert interviews was used to achieve each of our three research objectives. Pertaining to objective one, general information was gathered about their opinions of the inclusion of the three main sectors in environmentally conscious networks. For objective two, we gathered information about how education and academia involvement can help to create a network. In order to achieve objective three of determining the specific logistics of holding a workshop, we spoke with green chemistry experts who had experience with this in the past. The green chemistry experts interviewed were selected using the method of network sampling (Singleton & Straits, 2005). The questions we asked them are located in Appendix 1.

We conducted semi-structured interviews with these green chemistry experts (Singleton & Straits, 2005). Semi-structured interviews were chosen because some experts had more experience in certain areas and were able to elaborate more on particular topics. Similar to our other interviews, every effort was made to prevent our personal opinions and views from influencing the responses of our interviewees. In order to complete the network sample we first identified the most distinguished persons in the field of green chemistry, interviewed them, then asked for their suggestions about further contacts. We conducted telephone interviews whenever possible. Telephone interviews are more conducive to the semi-structured interview format than email (Singleton & Straits, 2005). However, due to the large time difference between Bangkok, Thailand and the United States, in some cases email correspondence was more feasible. Telephone interviews instead of face-to-face interviews were necessary because of the various locations of our interviewees.

After the interviews were completed, we compiled the data by grouping the answers into tables according to the questions asked. This compilation can be found in Appendix 8. After compilation, we analyzed the answers through content analysis (Singleton & Straits, 2005). We again used the process of observing similarities between the comments and by noting important differences of opinion for different questions. We then used this analysis as evidence for our findings in Chapter 5 in regards to the workshop logistics.

3.3.3. Archival Research

We also completed archival research on general workshop information and the advantages or disadvantages associated with different methods of teaching. This was accomplished by searching different journals of education. Some examples of these journals are: *Journal of Chemical Education, Engineering Education Journal, Journal of Professional Issues in Engineering Education and Practice, and the International Education Journal.* To identify these journals, we searched the World Wide Web for scholarly articles on chemistry education and workshops. In order to search for the specific articles that would help us understand the details of running workshops, and in particular chemistry workshops, we used keywords within the journal web search such as: workshop, seminar, outreach, and camp. We used the particular search engines of American Chemical Institute and Google Scholar. These articles provided insight into different activities and the success they had in other workshops based on the age groups we had identified.

In order to analyze these articles we extracted the material most relevant to our circumstances and compared the different ideas presented in each article, again using content analysis (Singleton & Straits, 2005). We also used archival research to compliment our findings obtained in the interviews with green chemistry experts and Chulalongkorn University chemistry professors.

3.4. Chapter summary

Through the methods discussed in this chapter we completed our three objectives:

1) To determine common elements of successful networks that incorporate government, and academia to promote environmental change.
2) To identify and recommend phases necessary in establishing a green chemistry network in Thailand.
3) To design a workshop which will contribute to the first phase of creating a green chemistry network in Thailand.

Completing these objectives was necessary in order to achieve our goal of making recommendations for establishing a successful green chemistry network in Thailand and to design a workshop that would initiate this process. In our next two chapters we present our findings obtained through the completion of these objectives, discuss the patterns that arose from our interviews and research of networks and workshops, then provide our recommendations derived from these findings.

4. NETWORK FINDINGS AND RECOMMENDATIONS

In order to achieve our goal of establishing a green chemistry network in Thailand and to design a workshop that would initiate this process, we had three objectives. One of them was to research successful networks and identify common characteristics between them. The second objective was to recommend phases necessary in establishing a green chemistry network in Thailand. This chapter illustrates the findings developed from the research of successful networks, and recommends phases that can occur in Thailand from these findings.

In this chapter we first discuss our findings of the main elements, or common characteristics, of a successful network. After developing these elements and presenting the data which led to their findings we incorporated them into our recommended phases that can occur in the creation of a green chemistry network in Thailand. Under each phase, we also recommend a number of specific actions that can be taken in order to complete the phase.

The data we analyzed in order to develop these findings stemmed mainly from interviews with network founders and from archival research on individual networks' databases. The compilations of this data can be found in Appendices 5, 6, and 7.

4.1. Network Findings

Our network findings achieved our first research objective of determining common elements of successful networks that incorporate government, industry, and academia to promote environmental change. We found six common elements within the seven networks we analyzed. These were: communication, education, academia involvement, industrial involvement, government involvement, and a core group of leaders. This section discusses each of these elements in detail and presents the data we used to reach these findings.

4.1.1. Finding: Communication between academia, industries, and government is a key element of successful networks.

The networks we analyzed all incorporated the participation of academia, industry, and the government in their actions. The communication linking these parties is a continuous aspect throughout the existence of a network. Communication is necessary to maintain trust and to promote the use of the ideals of the network.

The importance of communication about research can be seen in the future visions and goals of current networks. Table 4.1 demonstrates some examples of how communication is incorporated into a part of networks' missions.

Table 4.1. Communication as a major part of networks' missions.

Network	Mission
GIN	The Network seeks to create new concepts and a *new language* that will make it possible to extend our horizons and *communicate* across disciplines, nations, and sectors.
GCN	The main aim of the GCN is to promote awareness and facilitate education, training and practice of Green Chemistry in *industry, commerce, academia* and schools.
GCI	The mission of the Green Chemistry Institute (GCI) is to advance the implementation of green chemistry principles into *all* aspects of the chemical enterprise.
Ceres	Ceres' mission is to move businesses, capital, and markets to advance lasting prosperity by valuing the health of the planet and its people.
GSCN	The main mission of the GSCN is to promote R&D on Green & Sustainable Chemistry as a center of network, through such activities as promotion of *collaboration* including international activities, information exchange, *communication*, education and relevant proposals to funding agencies.
SVN	SVN's mission is to inspire a *community* of business and social leaders to build a just economy and sustainable planet.
NRC-EHWM	One of NRC-EHWM's main objectives is the development of a center of excellence to be a *forum* for environmental scientists and engineers to conduct research and develop new technologies.

In many cases, the goals of these networks are the very reasons they came into existence: to create communication between different sectors, in particular industry, academia, and government. The goal of the Greening of Industry Network (GIN), as stated by Kurt Fischer (2006), is "to make better *connections* between university, research, teaching, and government policies." The Green and Sustainable Chemistry Network (GSCN) (2000) specifically states "information exchange" and "communication" as a part of their mission. Also, the NRC-EHWM's (2005) main objective is to "be a *forum* for environmental scientists and engineers to conduct research and develop new technologies." These networks are examples of what we found to be "successful" networks, in that they have come a long way from their initial beginnings and have strengthened communication between companies, researchers, or other key groups of people.

In order to achieve these missions and goals of increasing communication, networks provide activities and conferences for their members. The Greening of Industry Network (2006) "provides an *open forum* for creative debate to engage researchers, business, workers, government, consumers and other actors in developing a shared understanding of the changes required for creating a more sustainable future." The Green Chemistry Institute (2006) "hosts *conferences* and coordinates efforts with an international network of green chemistry advocates" to increase communication about green chemistry on a global scale in order to work towards their mission of increasing green chemistry knowledge and use.

As a part of their goal, the Social Venture Network (SVN, 2003) seeks to create a "community of business and social leaders." SVN (2003) specifically states on their home page that, "Access to information is the key resource in any network" and that as a way to reach their goal, SVN "makes it easy for its members to get connected and provides the necessary tools for members to get relevant information fast." On an organizational level they "foster business partnerships and investments that forge new models for social-purpose enterprise" (SVN, 2003).

Another network, the Coalition of Environmentally Responsible Economies (Ceres) (2005), which promotes sustainable practices in industry, has a number of programs to increase communication between different industrial sectors. One of these is specifically an "industry" program which "brings investors and environmental experts together with companies and industries to find solutions to a range of environmental problems" (Ceres, 2005). This program coordinates communication between companies and those professionals concerned with studying the environment. Further data concerning the conferences and activities of different networks can be found in Appendix 5.

Through their actions of running conferences, which invite members from many different areas including government, academia, and industry, environmentally concerned networks focus on increasing the communication between these sectors. This element of communication mainly describes the communication between network members. Successful networks also communicate with people not involved with the network in order to promote their ideals.

4.1.2. Finding: Successful networks use education as a way to teach the public and network members about the ideals they represent

Four out of the seven networks we researched held education as a high priority and included it as a part of their mission. These included GCI, GCN, GSCN, and NRC-EHWM and can be found in Table 4.1. These networks also placed education as a specific category on their webpage, data located in Table 4.2 and in Appendix 5. Out of the seven networks we researched, three of them were specifically green chemistry networks and of these three, all of them had education as a category on their webpage.

We found two common methods of educating others about the ideals of the network. One was by supplying information on the website about the ideals the network is trying to promote, and providing materials in order to help facilitate the goal. Another method of educating others was through publications made available to members of the network.

The networks we analyzed specifically supplied information and materials about green chemistry on their webpage. The Green Chemistry Institute (2006) supplies information to "increase awareness and understanding of Green Chemistry principles, alternatives, practices, and their benefits within traditional educational institutions, and among practicing chemists and other scientists." To help increase the availability of green chemistry information, educational resources such as example reactions and specific green chemistry resources can be found on the Green Chemistry Institute's (2006) webpage.

The Green Chemistry Network in the United Kingdom also recognizes education as an important part of their network. They are creating a link for educational resources, similar to the one GCI has created, which will offer educational materials for teachers to use in their classrooms (GCN, 2006). GCN (2006) also has a new project called "Green Chemistry and the Consumer," which is "aimed at delivering knowledge and understanding of Green Chemistry to consumers and retailers, and covers all chemical-dependant consumer products including clothing, furnishing, electronic goods, personal care products and food."

Publicity was also a common method of educating others about the ideals of the network. Six out of the seven networks we researched used publications or their own journal to educate others about the recent activities of the network. For example, the Greening of Industry Network (2006) uses publication series in order to "extend the reach of the research and dialogue of our convenings." Table 4.2 shows which networks have publications.

Table 4.2. Networks' Education and Publications

Network	Link for Education	Publications
GIN	No	Yes
GCN	Yes	Yes
GCI	Yes	Yes
Ceres	No	Yes
GSCN	Yes	Yes
SVN	No	Yes
NRC-EHWM	Yes	Yes

As can be seen in the table, the three green chemistry networks we analyzed, GCN, GCI, and GSCN, all have publications and categories on their webpage for education. Green chemistry is still a new research topic in many fields, and in order to increase its use more people need to be educated about its benefits. One way of educating others about green chemistry, and the ideals of environmentally conscious networks, is by including academia in the network.

4.1.3. Finding: Networks incorporate the involvement of academia as a way to further research of the ideals of the network

Out of the seven networks we analyzed, five of the networks have a large academia sector. The networks that include industry can be seen in Table 4.3 below. The two networks, Ceres and SVN, that do not incorporate academia are networks specifically created to promote the ideas of sustainability in industry. They were created by industry leaders.

Table 4.3. Academia involvement

Network	Academia
GIN	Yes
GCN	Yes
GCI	Yes
Ceres	No
GSCN	Yes
SVN	No
NRC-EHWM	Yes

Dr. Kurt Fischer (2006) stated the importance of incorporating universities in the network as: "There job is to connect to the world. Sometimes current research is seen as irrelevant to university teachings, the network is trying to remedy this by incorporating them in it." About half of the members of the Greening of Industry Network are from universities which include faculty and graduate students (Fischer, 2006).

Each of the green chemistry networks we analyzed also incorporate the university as a main sector of their network. The Green Chemistry Network (2006) is based within the Department of Chemistry at the University of York in the United Kingdom. One of the primary objectives of the Green Chemistry Institute (2006) is "to advance research in Green Chemistry by promoting funding, increasing opportunities, and developing information on the benefits of green chemistry." Incorporating academia into the network helps to advance research on green chemistry and to develop further information on the societal benefits of green chemistry. GCI (2006) specifically includes members from academia on their advisory board. The Green and Sustainable Chemistry Network (2000) in Japan also includes academia as a main sector of their network.

In Thailand, a major part of the National Research Center for Environmental and Hazardous Waste Management (2005) is the involvement of universities. This network began with a consortium of five main universities in Thailand and is based out of Chulalongkorn University (NRC-EHWM, 2005). Currently, this network is increasing the involvement of graduate research in order to further their ideals (NRC-EHWM, 2005).

Although academia forms a large sector of each of these networks, it is not the only sector we found relevant. Academia serves as a way to further research on network ideals, but this does not always mean they can be implemented at the university setting. The involvement of industries in the network provides a way of actually implementing many of the ideas proposed by these environmentally conscious networks.

4.1.4. Finding: Including industries in the network serves as a way to implement the ideals presented by the network in industrial processes.

Some networks have a program within them specifically for industries. For example, the Green Chemistry Network (2006) has a "Green Chemistry Centre of Industrial Collaboration" which is used to help industries learn how to use green chemistry and to help with research.

Also, Ceres (2005) has an "industry program" and a "company program" which are used to teach industries about sustainable practices and to help them implement more sustainable practices.

For many networks, one of their reasons for forming was to increase more environment-friendly practices in industry. Although networks incorporate involvement from many different sectors, industries typically can have the largest impact in making changes to their processes because they are currently the main producers of waste. Dr. Kurt Fischer (2006) from the Greening of Industry Network stated, "Industrial developments are the biggest influences on environmental change these days." Each of the networks we researched had strong industrial membership. Table 4.4 shows the main inclusions of industry, more detailed information can be found in Appendix 5.

Table 4.4. Networks and Industry

Network	**Industrial Involvement**
GIN	International association of researchers and business leaders
GCN	Have a "Green Chemistry Centre of Industrial Collaboration"
GCI	As a part of its mission aides companies with industrial implementation of green chemistry
Ceres	Coalition includes over 80 investor, environmental and public interest organizations united
GSCN	*Website is under construction*
SVN	Members are CEO's, founders and senior executives of some of the most progressive companies in the world
NRC-EHWM	Currently attempting to increase industrial involvement through joint research projects with graduate students.

Each of these networks, except for one, incorporate industry. Along with some networks developing programs for industries, they also include them as a major sector of the network. The Green Chemistry Institute (2006) includes industries as a way to increase "industrial implementation of green chemistry." Also, the Greening of Industry Network is comprised of about 20% industrial involvement (Fischer, 2006). The Social Venture Network (2003) is entirely composed of industry with members being "CEO's, founders and senior executives of some of the most progressive companies in the world."

Dr. Somporn Kamolsiripichaiporn (2006), whose interview can be found in Appendix 6, is the director of the National Resource Center for Environmental Hazardous and Waste Management (NRC-EHWM) and head of the Asia branch of the Greening of Industry Network.

She felt that although NRC-EHWM is mainly the consortium of five universities, one of its main agendas is to increase industrial interest in hazardous waste management (Kamolsiripichaiporn, 2006). They are currently attempting to do this by increasing collaboration with industry for research with graduate students.

The involvement of industries forms one element of a successful network. Many industries need further motivation in order to join the network because they are not willing to share their processes with others (Haack, 2006). One way to motivate industries to join the network is by including the government and policy makers in the network.

4.1.5. Finding: Government support and involvement is used to motivate further research and practices of the network ideals.

Advantages of involving the government in the network include adding credibility, supplying funding and grant opportunities, and the possibility of affecting policy. Another important aspect of including the government is to sponsor awards for the use of the ideas the network is representing. These awards motivate more researchers and companies to study and use more environment-friendly practices that follow the twelve principles of green chemistry (Anastas, 2006).

The green chemistry networks we analyzed each incorporated awards for green chemistry in their respective nations as a part of the network. The Green and Sustainable Chemistry Network (2000), with the sponsorship of the government, offers awards for the production and implementation of green and sustainable chemistry practices. Their awards are sponsored by the "Minister of Economy, Trade and Industry, or by the Minister of the Environment, or by the Minister of Education, Sports, Culture, Science and Technology" (GSCN, 2000). The awards offered by the Green Chemistry Network (2006) are sponsored by the Crystal Green Chemical Technology Faraday Partnership which is a government-run organization that promotes the use of green chemistry in the United Kingdom. The Green Chemistry Institute's (2006) awards are sponsored by the United States EPA. A list of the awards is located in Table 4.5.

Table 4.5. Green Chemistry Networks and Available Awards

Green Chemistry Network	Awards/grants
GCN	▪ Crystal Faraday Green Chemical Technology Awards ▪ UK Awards for Green Chemical Technology
GCI	▪ Presidential Green Chemistry Challenge Awards ▪ Joseph Breen Awards ▪ Kenneth G. Hancock Memorial Award
GSCN	▪ GSC Student Travel Grant Awards started in 2004 ▪ GSC Awards started in 2001

Along with incorporating government into the network to provide awards as incentives, the government is also important to include because they are the policy makers of society. They also have the ability to supply funding to a network. The National Research Center for Environmental and Hazardous Waste Management (2005) was established through a government fund from the Asian Development Bank (Kamolsiripichaiporn, 2006).

Many networks are sponsored by governments, or include policy makers as an influential sector of their organization. The Green Chemistry Institute (2006) was formed through the United States Environmental Protection Agency. About 20 % of the members of the Greening of Industry Network are governmental in nature (Fischer, 2006).

These past three elements described who is commonly involved in environmentally conscious networks. These networks use the elements of communication and education in order to strengthen the ties between academia, industry, and government. In order to do this, these networks need a core group of leaders to organize events that increase collaboration.

4.1.6. Finding: A core group of leaders maintains organization and manages communication of the network

Each of the networks we researched had some form of a core group of leaders. The formal name of these leaders varies between networks. Common names included: “steering committee”, “governing board”, “board of directors”, or “management team.” Regardless of the name, each of these boards serves the same purpose, which is to maintain the network and keep all members informed of its activities. Details about the various core leaders can be seen in Table 4.6.

Table 4.6. Networks' Core Leaders

Network	Core Leaders
GIN	*Steering Committee*; *International planning board*; 3 General Coordinators
GCN	13 members on *Advisory Board*
GCI	13 members on GCI *Governing Board*
Ceres	27 members on *Board of Directors*
GSCN	Number of members on different boards
SVN	5 members on *Management Team*
NRC-EHWM	Started with researchers from consortium of 5 universities in Thailand

The Green Chemistry Institute (2006) has members on its governing board from each of its sectors: government, industry, and academia, to "reflect a broad set of environmental interests and capabilities." By representing these different sectors, the governing board includes the combination of the differing viewpoints that may exist.

Both Dr. Kurt Fischer (2006) from the Greening of Industry Network and Dr. Paul Anastas (2006) from the Green Chemistry Institute specifically stated the importance of this select group of people. Dr. Kurt Fischer (2006) stated that he started the Greening of Industry Network by "finding a small core of people with mutual interests who were willing to work on it because it was a part of their life goals or jobs." Dr. Paul Anastas (2006) stated that it was important to bring the people interested together in order to raise public awareness. The Green Chemistry Institute began with six co-founders in 1997 (Anastas, 2006). A more in depth compilation of their interviews can be found in Appendix 6.

Another important idea behind combining the resources of a small group of interested people is that a group has much more power in terms of validity to the public, industry, and government than the ideas of one or two people have. The Greening of Industry Network (2006) started with a core of about twelve people so that ideas being presented were not only from Dr. Kurt Fischer and Dr. Johan Schott, who were the two men who initially formulated the idea for this network.

An additional example of a network starting with a group of interested people is the National Resource Center for Environmental and Hazardous Waste Management in Thailand (2005). This network began with researchers from five different universities in Thailand in order to help educate others about hazardous waste management. By having a collaboration of five universities proposing this network, they attained a much higher status in the view of the public, academia, and government. This allowed them to receive significant funding from the Asian Development Bank in order to expand their network and research (NRC-EHWM, 2005).

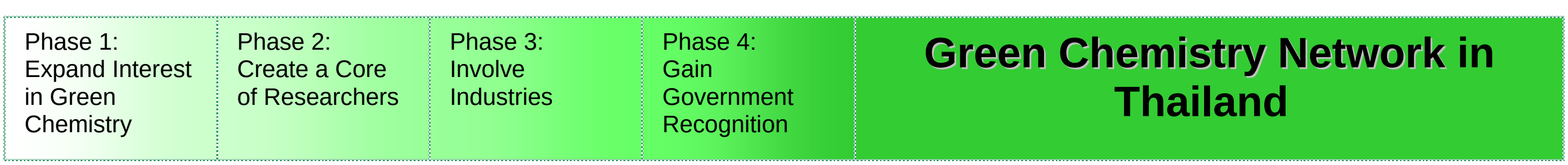
In summary, the six key elements we found of successful networks are communication, education, academia involvement, industrial involvement, government involvement, and a core group of leaders. These elements completed our first research objective which was "to determine common elements of successful networks that incorporate government, industry, and academia to promote environmental change."

4.2. Network Recommendations

We incorporated the six main elements we found of successful networks into our recommendations of four main phases of action needed to create a green chemistry network in Thailand. This completed the first part of our project goal: "to make recommendations for establishing a green chemistry network in Thailand." After making these recommendations we achieved our second research objective under this project goal which was: "to identify and recommend phases necessary in establishing a green chemistry network in Thailand."

We recommend that the first logical phase to complete at Chulalongkorn University be to expand increase interest in green chemistry. We recommend the second phase be the creation of a core group of green chemistry researchers that will act as an initial board of directors for the network. The third phase of the network should be outreach to industry and educating companies about green chemistry and how it can benefit them. The fourth phase we recommend is to involve the government in the network. A diagram of these phases can be found in Figure 4.1. The element of communication is an element that needs to be continuous throughout the phases of the network and therefore we are not recommending it as a specific action. However, we do recommend that this is always in the forefront of the mind of the network leaders.

Figure 4.1. Recommended order of phases to creating a green chemistry network in Thailand



4.2.1. Recommendation: Phase one should be to expand interest in green chemistry.

Green chemistry is still a very new topic of research, and many researchers and students have not heard of it. Before creating a green chemistry network, people need to be aware of the basics of green chemistry. By increasing the interest of researchers and students in green chemistry, involvement in the network in the future will increase

There are different approaches in which to educate others in green chemistry. One way we recommend was to hold workshops for other educators such as professors. Hopefully this will encourage professors whom will be interested enough to begin incorporating green chemistry into their classroom and possibly perform research. This has already been done in Thailand with a workshop in 2002 presented by Dr. John Warner from the University of Massachusetts and Dr. Paul Anastas from the Green Chemistry Institute (Tantayanon, 2006).

Providing an introductory workshop for students is another way to enhance interest and knowledge in green chemistry. This should come after the workshop for professors in order to have people interested in running the workshop. The importance of a workshop for students is to increase knowledge and interest in green chemistry in hopes that they will choose to study it further in their education or careers.

Another important part of holding a workshop to advance interest in green chemistry is to think about what occurs following the workshop. This not only includes keeping the further phases in mind, but also the general goal of the green chemistry network we want to create. Many of the green chemistry experts we interviewed emphasized keeping the overall goal in mind. Dr. Ed Brush (2006) stressed this idea by saying, “You need a plan or strategy. I think that a seminar or seminar series is a great idea, but what will be the follow up? As I wrote above, you still need faculty involvement to keep the momentum going” and “the thing that got green chemistry going at BSC was a seminar by Dr. John Warner on green chemistry. But that alone is not enough. You need faculty who really butt into the idea to keep it going.” Dr. Julie Haack (2006) also reinforced the idea of always thinking about what will come next. When asking her if she felt a green chemistry workshop for students would be a strong starting place for green chemistry at the university she said, “Depends on you’re your goals are. What do you want the seminar to do? Do you want to stimulate interest in green chemistry by educating the students so that they will put pressure on faculty to teach it?” (Haack, 2006).

We recommend the following actions within this phase:

1. Educate other educators about green chemistry through seminars or lecture series.
2. Incorporate the next phase by increasing involvement of those educators very interested in green chemistry with the overall plan.
3. Hold workshops for students in order to increase their interest in green chemistry in hopes they may complete future research in this field.

Further discussion of the workshop we developed for undergraduate students is located in Chapter 5. These actions were mainly developed through our interview with Dr. Paul Anastas which can be found in Appendix 7.

This phase incorporates the elements of communication, education, and academia involvement. Communication is involved in expressing the ideas of green chemistry to others. Teaching students and professors about green chemistry incorporates the element of education. By completing this phase at the university setting, and including professors and students in the workshops, the element of academia is included.

4.2.2. Recommendation: Phase 2 should be to create a core group of green chemistry researchers to act as the board of directors for the network

Many networks were started with a core group of researchers. This was a small group of people who spent a large amount of effort expanding the network and increasing others' knowledge of the network's purpose. This core of researchers can form a board of directors, or advisory board, for the network and can serve to run the network and to maintain the communication throughout the sectors involved via organization of different activities.

We recommend that this phase occur second because of the need for increased interest in green chemistry to occur first. However, in order for phase one to be completed there does need to exist one or two people who are acting as leaders in the green chemistry movement we are proposing occur in Thailand. In this phase, we recommend expanding these leaders to include more people as a way to add credibility and respect for the future network.

In order to move through this phase we recommend the following actions be taken:

1. A definitive leader or a few leaders that want to start the green chemistry network should plan a conference on green chemistry for other researchers.

2. In order to decide who to invite to the conference, the leaders should go to other universities in Thailand and identify who is practicing green chemistry research. In some cases, researchers may actually be doing green chemistry, although they are unfamiliar with the term green chemistry or the theory behind the approach.
3. At the conference, the leaders should introduce these researchers to the term green chemistry, and the guiding principles. Then, they can propose the creation of a green chemistry network in Thailand.
4. From this conference try to motivate a core group of researchers, 6 to 12 people, to join the network and become the initial board of directors for the network. They should be willing to put a lot of effort into the creation of this network.
    - More researchers than this can be involved, but first and initial core board of directors is needed.
5. Also, follow-up conferences should to be held to continue reinforcing the benefits of green chemistry and the reasons for creating a network.

These are the specific actions that should occur during this phase in order to create an initial board of directors for a green chemistry network in Thailand. These actions were developed through our interviews with Dr. Paul Anastas, Dr. Julie Haack, Dr. Kurt Fischer, and Dr. Somporn Kamolsiripichaiporn.

The key elements of education, academia involvement, a core group of leaders, and communication are also a part of this phase. In this phase, education is used to help express the idea of green chemistry to other researchers who are already studying environmental-friendly processes. The people invited to the conference are researchers from universities which is the element of academia involvement. In this phase, the core group of leaders which will organize the ideals of the members of the network and will be able to schedule events for network members was formed. Communication in this phase is used by teaching others about the ideals of the network and promoting the importance of green chemistry in Thailand.

4.2.3. Recommendation: In phase 3, the network should involve industries through outreach programs

After phase two, a core group of researchers was formed. This core group can now promote the network to others. In this phase we feel that industries should now join the network.

In order to increase industrial involvement we recommend that the core group of researchers go to individual companies and present the importance of green chemistry and how it can help that specific company economically, and how it can help society and the environment. As a follow-up to this initial personal contact we recommend holding a general conference for these same companies which demonstrates current green chemistry processes in use around the globe. At this conference, the core group of green chemistry researchers described in Section 4.2.2, should present their ideas and goals for the future of forming a green chemistry network in Thailand. They would make the case for using green chemistry practices, and hopefully would start to increase interest in the use of green chemistry in industry.

The Greening of Industry Network reached out to industries as their next phase after creating their core of leaders (Fischer, 2006). Their first official conference was held in 1991 and involved an open meeting with about 70 people in attendance from different companies, educational institutions, and government organizations (Fischer, 2006). The idea of this conference was for everyone who attended to bring their ideas for the future of the network and for what they would like to see occur. Kurt Fischer (2006) felt that this first conference was "based mostly on people's interest, not so much who they were, and their willingness to work on the issues."

To complete this phase we recommend the following actions take place:

1. Send core group of green chemistry researchers to industries.
2. Present the subject of green chemistry, how it can help them economically, and how they can help society and the environment by implementing greener practices.
3. After presenting green chemistry to each company individually, invite all of them to see what green chemistry research is currently happening around the globe at a seminar at Chulalongkorn University.
4. Invite them to join network
    a. Offer to help them with green chemistry research for their respective processes.
    b. Offer collaboration with university researchers and students in order to help with research.

One limitation to these methods of increasing industrial involvement in the network was raised by Dr. Julie Haack in an interview on February 24, 2006: "What happens when businesses don't want to share their intellectual properties?" Many industries do not want to share information about their processes because they are competing with each other. They do not want to collaborate with the competitor. One way Dr. Haack (2006) recommended avoiding this was by having the leader of the network offer to sign disclosure agreements with the companies about their individual processes.

This phase incorporated the key elements of industrial involvement, core group of leaders, education, and communication. This phase is where we recommend first including industry in the network. This is an important aspect of the network in order to have a stronger affect on the environment by implementing green chemistry practices in industry. The core group of leaders is still an element of this phase and continues to be throughout the existence of the network. Education in this phase represents teaching the companies about green chemistry and how it can help them and society. As always, the element of communication is still a main part of this phase. In this phase communication incorporates speaking with individual companies and with maintaining contact with them after the first contact is made.

4.2.4. Recommendation: Phase 4 should be to develop government recognition and communication

After phase three, another way to motivate industries to join the network is to incorporate government involvement. Reasons for including the government in the network at this phase are for increased funding, grants, and award opportunities. Also, the government creates policies and has the ability to place stronger control on the import and record of chemicals in Thailand.

Awards from the government are important as a way to provide incentive to industries and researchers to use or study green chemistry. Paul Anastas (2006) specifically stated that one of the main steps in creating a successful green chemistry network is to "establish a national award to recognize accomplishments in green chemistry for industries." Anastas (2006) has created an award like this in many countries with the spreading of the Green Chemistry Institute. These include the United States, Japan, and the United Kingdom. The award in the United States is called "The Presidential Green Chemistry Challenge" (GCI, 2006). This award recognizes individuals in many different areas of green chemistry. Kurt Fischer (2006) also noted how people like to be rewarded for their work. He strongly recommended keeping in mind that "people are rewarded for solo work a lot in academia" (Fischer, 2006). Although there is discussion of partnerships, people still are given recognition on a mainly individual basis (Fischer, 2006). An award that commends the collaboration between industries and universities would help to increase partnerships.

In order to increase government involvement, we recommend the following actions:

1. The core group of leaders should ask the government to sponsor a national award in order to motivate industry and universities to increase green chemistry implementation and research.
2. Once communication is initiated with the government, maintain communication to increase funding opportunities instead of losing them.
3. Use the products of funding to build back into green chemistry education of students.
4. Invite representatives from other nations who have strong regulations to speak with Thailand's government in order to form collaboration with other governments

These actions were developed from recommendations made by Dr. Paul Anastas whose interview can be found in Appendix 7.

This phase incorporated each of the six elements we found in Section 4.1 of this chapter. This phase once again utilizes the importance of the core group of green chemistry researchers through their ability to communicate with those outside of the network and to promote the network to others. All three sectors, academia, industry, and government, are a part of this phase. One of the main reasons for including government involvement is to motivate further academics and industries to join the network. Education is still a main element of this phase through creating an understanding within the Thai government of the importance of green chemistry in society. Communication is the key element of this phase, as it is throughout the existence of the network.

Once government, industries, and educational institutions are involved, the network will have more force in encouraging others to study and use green chemistry. As the network grows, and funding increases, the network can increase its educational aspect (Anastas, 2006).

4.2.5. Recommendation: Throughout these phases, always keep the overall goal of the network in mind.

Keeping the goal of the network in sight throughout its creation lends to a clearer path to follow. We recommend the following goal for this network: To unify industry, academia, and government into achieving a common goal of increasing green chemistry use, education, and policy in Thailand. This goal incorporates communication with unifying the different sectors. It utilizes the importance of the involvement of the three sectors of industry, academia and government in the network. It also includes education about green chemistry in Thailand and its implementation through industrial processes. The core group of green chemistry researchers have the ability to tie the network together and will be able to push the creation of the network until it successfully achieves this goal.

4.3. Chapter Summary

In this chapter we first discussed the six common elements we found through our analyses of successful networks. We then described how we incorporated these six elements into our recommendations of four main phases of creating a green chemistry network in Thailand. By finding these elements and recommending phases that can occur in Thailand we completed the first part of our project goal of "making recommendations for establishing a green chemistry network in Thailand."

There are a number of limitations involved with our findings and recommendations in this chapter. Our findings of the common elements are limited to the sample of networks we analyzed. We analyzed a total of seven networks, and two of them incorporated a much larger proportion of industry than academia or government.. The phases we recommended are limited to our understanding of the culture in Thailand and how it compares with that of the location of the networks we analyzed. We were also limited in gaining a broader understanding of more definite actions within the phases due to the short duration of out project and our stay in Thailand. All networks are created in different ways depending on the situation, and it is difficult to accurately map out the specific steps that need to be taken in Thailand to create a green chemistry network.

In order to make the abstract idea of the first phase become a reality, we developed the next action that can occur within this phase in Thailand in Chapter 5. This action is a workshop for students to increase their knowledge in the subject of green chemistry. The next chapter describes our findings on specifics of our recommended workshop including logistics such as purpose, length, schedule, budget, age group, and attendance.

5. WORKSHOP FINDINGS AND RECOMMENDATIONS

This chapter covers the findings which led to our workshop recommendations. From our findings, we recommended a one day undergraduate level workshop as the optimal combination of target age group and workshop length to serve as the next step in phase one of establishing a green chemistry network in Thailand. Later in the chapter, we cover the necessary logistics of our recommended workshop. These logistics include the purpose of the workshop, type of workshop, schedule, attendance, budget, and publicity. In the latter part of this chapter, we also provide information about alternative workshops of various lengths and target age groups. These workshop options enable our sponsor to reach students of various age groups, thereby diversifying efforts to increase knowledge of green chemistry among students. Choices of an outreach program, alternative workshop, or even a summer camp are provided. The findings that motivated our recommendations were reached from analysis of interviews with Chulalongkorn University chemistry professors, green chemistry experts, network founders, and archival research.

5.1. One Day Undergraduate Workshop on Green Chemistry

Holding a one day long workshop for undergraduate students is the next action that should be taken within the first phase described in Chapter 4 for starting a green chemistry network. In this section, we first discuss our target age group findings followed by our recommendation for the optimal age group. Next, we explore our findings with respect to length of time, and our subsequent recommendation from these findings.

5.1.1 Recommending the optimal target age group

Finding: Chulalongkorn professors feel it is necessary for students to learn green chemistry prior to starting their careers.

Eight of the ten Chulalongkorn professors we interviewed expressed this view. Professor 4 explained that "It is important and necessary for undergraduate students to learn about green chemistry." Also, as stated by professor 1, "It is necessary for university students to learn green chemistry before entering industry." Note that of the ten professors we interviewed, one was unfamiliar with green chemistry, and one did not feel green chemistry was important to learn in the classroom. Professor 6 felt that "Green chemistry should be added into other classes." The remaining eight professors felt that students needed to learn about green chemistry so that they can better understand how their actions as a chemist can effect the environment. Professor responses are summarized in Table 5.1.

Table 5.1. Professor's feelings towards benefit of green chemistry to students.

Professor	Green Chemistry applicable to students?	Workshop effective in increasing green chemistry use at Chulalongkorn?
1	It is necessary for University students to learn green chemistry before entering industry.	Agrees that a workshop is a good starting place for green chemistry at Chulalongkorn University.
2	Green chemistry should be introduced in Universities, maybe introduction lab courses.	*non-response*
3	Yes, good idea.	A good idea
4	It is important and necessary for undergraduate students to learn about green chemistry.	Effectiveness of workshop will depend on contents
5	Small scale labs-good for qualitative illustration but not quantitative evaluation	Should also be offered to high school students, and non-Chulalongkorn students
6	Green chemistry should be added into other classes	Good idea.
7	*Did not know what green chemistry is*	*Did not know what green chemistry is*
8	Yes, I think it does.	Yes
9	Thinks student should learn it	Yes, but should start with graduate students
10	Does not expect this, because it is just an ideal system, not real life, once students learn this will laugh at you because they cannot apply it	Thinks good so when go to work will have something to remind them that they need to benefit world and not just themselves

Finding: Knowledge of basic chemistry is necessary to fully understand green chemistry theory and practice.

According to Professor Julie Haack (2006), green chemistry application is most easily understood when used in an organic chemistry laboratory. Chemistry students at Chulalongkorn University typically do not study organic chemistry until their second year (Tantayanon, 2006). Also, professors 2 and 4 explicitly stated that any future course offerings in green chemistry at Chulalongkorn University should be for 4th year undergraduate students. These professors both reasoned that students need a prior knowledge of chemistry in order to fully understand green chemistry. Professor 2 stated that “2^{nd} year students are too young to really understand it.” Professor 2 then identified 4^{th} year students as the most appropriate audience for a green chemistry course. Professor 4 said “a green chemistry undergraduate course should be for 4^{th} year students.” The other eight professors interviewed did not state their opinion on which age is best. Complete responses are available in Appendix 4.

Finding: Many Chulalongkorn University chemistry students would be interested in learning green chemistry.

Five of the ten professors we interviewed expressed this view. Professor 4 felt that “students want to learn green chemistry, because students want to know what happens in industry in real life.” Also, professor 9 had this opinion: “Some students [will be interested in green chemistry] because in chemistry if you have a variety of subjects and green chemistry is one of the courses some of them will have interest in.” Note that three of the professors did not explicitly answer this question. One professor was unsure about student interest in green chemistry and one professor said that students are not interested in green chemistry but might be if they knew more about it. Summaries of professor responses are in Table 5.2 and Appendix 4.

Table 5.2. Professor opinions about student interest in green chemistry

Professor	Response
1	Feels that necessary for university students to know [green chemistry] so that they can suggest the idea to their boss.
2	*non-response*
3	They might not know what it is; there should be a campaign to raise awareness.
4	Thinks students want to learn green chemistry, because students want to know what happens in industry in real life. Effectiveness of workshop will depend on contents, essential that workshop be interesting, fun, funny, not too hard
5	Students are generally interested in helping the environment, but has not spoken to students about green chemistry
6	They will think green chemistry is interesting initially, continuing interest depends on the professor.
7	*Did not know what green chemistry was*
8	Yes
9	Some students [will be interested in green chemistry] because in chemistry if you have a variety of subjects and green chemistry is one of the courses some of them will have interest in.
10	When Professor 1 offered research on green chemistry, she did not attract any undergraduate students; they did not know what it was and were uninterested in applying time to something they were unfamiliar with

Recommendation: A green chemistry workshop should target undergraduate level students.

This recommendation came from consideration of the three findings described above. Designing the workshop for undergraduates effectively addresses each of the issues raised by these three findings: professors feel green chemistry is necessary for students to learn, younger students do not have the adequate background to understand it, and many undergraduate students would be interested in learning green chemistry. Also, undergraduate students will soon graduate and move into industry where their knowledge of green chemistry could aid in industrial interest in green chemistry. This is a key phase to the creation of a green chemistry network as described in Chapter 4.

5.1.2 Recommending the optimal workshop length

Finding: Most undergraduate students at Chulalongkorn University have limited or no understanding of green chemistry.

Seven out of the ten professors we interviewed thought it was unlikely that Chulalongkorn University students were familiar with green chemistry. For example, professor 3 stated that "[students] might not know what [green chemistry] is; there should be a campaign to raise awareness." Further evidence for the lack of student knowledge about green chemistry is that when a Chulalongkorn University professor offered research in green chemistry, no students inquired about the opportunity. Professor 10 felt this was not due to lack of interest, but due to lack of familiarity with green chemistry in the first place. Professor 10 explained this reasoning by saying "When professor 1 offered research on green chemistry, she did not attract any undergraduate students; they did not know what it was and were uninterested in applying time to something they were unfamiliar with." More detailed information is located in Appendix 4.

Finding: Students are unlikely to attend a workshop if they simply view it as extra work.

Professor John Warner (2006) thought that since Chulalongkorn University students are mostly unfamiliar with green chemistry, their attendance is dependant on their perception of what the workshop will be like, specifically stating "be careful how you sell it, people are quick to reject things they don't know much about." Chulalongkorn University chemistry professor 4 expressed a belief that "it is essential that workshop be interesting, fun, funny, not too hard" Professor Julie Haack (2006) felt that a workshop longer than one day would demand an unreasonable amount of time from students, especially since green chemistry is unfamiliar to many of them. In an interview with her she stated: "it will be very difficult to get undergraduate students to give up a weekend or a lot of free time" (Haack, 2006).

Recommendation: The workshop should be one day in length.

After consideration of the two findings above, we recommended the duration of our proposed workshop be one day. This addresses the issues raised by our findings: Chulalongkorn University students have very limited understanding of green chemistry and students will not attend a workshop if they perceive it as extra work.

We recommend a one day undergraduate level workshop on green chemistry. This combination of time commitment and age group is optimal for creating a starting point for a green chemistry network in Thailand. In the next section, the logistics of our recommended workshop are developed, followed by a discussion of the advantages and disadvantages of workshops for other ages and various lengths.

5.2. Recommendations for Workshop Logistics

In the previous chapter we recommended that the first phase in creating a green chemistry network is to hold workshops as a way of incorporating the element of education. In the previous section, we illustrated our recommendation to have a *one day workshop for undergraduate students*. To further assist our sponsor in shifting the *first phase* of implementing a green chemistry network into a *tangible event*, we researched specific workshop logistics and made recommendations that can assist her in this process. This section illustrates the findings and recommendations for *the purpose of the workshop, type of workshop, attendance, funding* and *budget,* and *publicity.*

5.2.1 Goal of Workshop

Finding: The past workshops held by educators have all had the common goal of increasing student knowledge of the workshop's subject.

The previously held workshops we researched came specifically from Chulalongkorn University chemistry professors as well as from programs held around the world. These workshops, camps, and outreach programs all make the similar connection of creating their goal to create interest to their subject.

From our interviews of Chulalongkorn University chemistry professors, we collected the goals of the past workshops from the pamphlets that were used for publicity, funding, or handed out during the workshop. Table 5.3 illustrates the goals of these workshops. These goals were originally in Thai and had to be translated to English. The exact wording of the English goal created a limitation because the Thai wording did not give a direct translation in every case. Although these goals are all composed of different subject matter, they have the common theme of giving knowledge about the workshop's subject.

Table 5.3. Goals of past workshops held by Chulalongkorn University chemistry professors

Workshop Name	**Goal**
Chitin and Chitosan	To give the knowledge of the Chitin and Chitosan and *teach the audience* about the technologies of Chitin and Chitosan, to provide information in laboratories and lectures, and to share ideas between audience, lecturers and professors
Small Scale Chemistry for High School Teachers	To *give knowledge* about small scale chemistry laboratory workshop for high school teacher
Capillary Electrophoresis	To *give the knowledge* in the capillary Electrophoresis and to give the audience pride in their research and lectures

We extended our research of workshop goals beyond Thailand to broaden the scope of our findings. We achieved this through archival research of workshops and other types of outreach programs. The workshops located in Table 5.4 also have the general theme of giving knowledge about the workshop's subject. Although these workshops and outreach programs are offered in different contexts, they relate to each other by providing similar goals.

Table 5.4. Examples of global camps.

Camp or Workshop Title	Location	Goal of Program
2001 CE Summer Camp	Kanpur, India	The objective of the camp was to provide an exposure to technology through motivation, personality development, fun-filled schedules, and excursions.
Camp Reach at WPI	MA, USA	Goal is to generate or sustain *interest* in engineering and technology and to enhance self-confidence and motivation toward education.
Enrichment Program	Michigan, USA	Eighth grade two-day engineering enrichment program to increase the average student's *interest* in technical disciplines.
Interactive Analytical Summer Camp for Middle School Girls	N. Carolina, USA	The goal of this camp is to provide girls with a unique opportunity to experience analytical chemistry in a way that will spark their *interest* in how it is studied, its roles in modern scientific research, and the diversity of educational and career opportunities that science has to offer.
Science Days	Texas, USA	It is the goal of this program to encourage student *interest* in the sciences at an early age.
Postgraduate Summer School on Green Chemistry	Venice, Italy	Its aim was to teach young graduate and postgraduate chemists from different European countries how to approach pollution prevention from a chemical standpoint.

Many of the workshop goals specifically include the word "interest" which is italicized to show emphasis in Table 5.4. Although this is not an exhaustive list, these camps and many others we researched were created in order to attempt to instill a greater interest and knowledge in the subject in its participants.

The workshops and camps we researched were specifically for the student age group, and not for adults or other educators. It is possible that in workshops held for other educators that the main purpose is not to increase interest, but for other reasons. However, the workshop we developed is specifically aimed at students and therefore we felt it was most applicable to research these types of workshops.

Recommendation: We propose the following purpose of a one day green chemistry undergraduate workshop: To generate interest in undergraduate students in green chemistry by providing educational lectures and interactive laboratories.

The purpose of the workshop extends further than simply educating undergraduates about green chemistry. It serves a larger goal of one action in leading towards the formation of a green chemistry network in Thailand. This recommendation also ties into the first phase of creating a network by educating students and creating interest about green chemistry.

5.2.2. Type of Workshop

Finding: Interactive laboratories are the best way to maintain interest in the audience during workshops.

Experts such as Professor Julie Haack (2006) from the University of Oregon and Professor John Warner (2006) from the University of Massachusetts, believe that hands-on laboratories reinforce the ideas presented in lecture. From Dr. Julie Haack's (2006) interview in Appendix 9, she states on the subject of green chemistry, "it's one thing to hear about it, it's another thing to do it." She also points out that laboratories emphasize communication between students and in the context of a workshop held outside of school, "a laboratory is a relaxed atmosphere" to learn in (Haack, 2006). Laboratories provide visual aids that illustrate the reaction (Haack, 2006). "Labs such as the carbon dioxide lemon peel are a great undergraduate laboratory because they are not too technical and still provide a high visual aid where students can see the reactions taking place" (Haack, 2006).

Haury and Rillero (1994) agree that there are many benefits of interactive learning. They exemplify this in "Perspectives of Hands On Science Teaching", where they develop the "benefits for students are believed to include increased learning; increased motivation to learn; increased enjoyment of learning; increased skill proficiency, including communication skills; increased independent thinking and decision making based on direct evidence and experiences; and increased perception and creativity" (Haury & Rillero, 1994, p. 6). In addition they make the case that hands-on learning makes education fun for both the students and the teacher (Haury & Rillero, 1994).

Four Chulalongkorn University chemistry professors from our interviews in Appendix 4 also thought interactive laboratories were important. Professor 5 thought that a green chemistry workshop should "include both lecture and hands-on activities." Professor 2 stated that, "workshops should be interactive," while professor 6 points out that student should engage in activities and the workshop should focus on, "not being boring." Five out of the ten professors interviewed also have held interactive workshops that all had combined lecture and laboratory components.

Recommendation: A small lecture portion and a large laboratory component should be used for the undergraduate student workshop.

A small lecture portion will give students an introduction to green chemistry theory and explain the laboratory activities. The laboratory component will provide first-hand experience with running green chemistry reactions, and will highlight the 12 principles of green chemistry covered in the lecture. The anticipated outcomes of the laboratory exercises are to help students learn, become interested in green chemistry, and to encourage independent thinking.

5.2.3. Attendance

Finding: Small attendance workshops are more conducive to in-depth learning.

Mechanical engineering Professor Chrysanthe Demetry (2006) from Worcester Polytechnic Institute is the co-founder of a summer educational program for middle school students titled *Camp Reach*. During our interview with her, she explained that Camp Reach accepts only thirty students per year in order to ensure a high faculty to student ratio (Demetry, 2006). By accepting only 30 students, the staff can form a personal relationship with the students and the number is more "manageable" for labs and experiments (Demetry, 2006).

Professor Julie Haack (2006) also believes that smaller sized workshops are the most effective way to help students improve their skills and understanding of a given topic. In our meeting with her on Feburary 24, 2006, she explained that this is the reasoning for limiting the size of the annual green chemistry workshop at the University of Oregon. Also, she specifically stated that she believes our proposed workshop would be most beneficial if kept to a size of approximately 20 students (Haack, 2006).

Recommendation: The number of attendees for the undergraduate workshop on green chemistry should be 20 to 30 students.

This is the first workshop of its kind in Thailand, and therefore our recommendation is to start with a small group of students. By focusing on a small group of students, lectures and laboratories are more personal and have more influence on the students. This will encourage students to ask more questions and become engaged in the material, increasing the effectiveness of the workshop.

5.2.4. Funding and Budget

Finding: The funding for this workshop can come from a number of different sources.

Many workshops held in the past in Thailand have been sponsored by private companies, financed through various grants, or funded by the government. Grants available for a workshop held in Thailand include the Green Chemistry Institute's Developing/Emerging Nations Grant located in Appendix 15. Funding for workshops held in the past have also come from Thailand's government and private companies. From our interviews with Chulalongkorn University chemistry professor 8 stated that "the ministry of science and technology is where I receive funding" while professor 1 stated the camp they planned "was funded by a government grant." The complete interviews of these two professors is located in Appendix 4, Workshops were sponsored by private companies as stated by professor 9 who received "funding for the workshop from Beckman Coulter and PCL holding Company."

Finding: The sample budget for a one day workshop for undergraduates located in Table 5.5 is 240,000 Thai Baht (6000 US dollars).

We based this finding on the costs of other workshops with similar material and spatial needs located in Appendix 13. Our sample budget is based on a workshop that can be held at Chulalongkorn University.

Expenses are broken down into the five following categories: people, location, food, materials, and publicity. At the current date of March 1, 2006, one U.S. dollar is approximately equivalent to 39.40 Thai Baht. The people category contains three lectures at 3,000 Baht per hour, three laboratory assistants at 300 Baht per hour, and the fares to fly international lecturers from around the world into Bangkok. The location is based on the workshop being held at Chulalongkorn University at a 1,000 Baht per hour rate.

Food for a one day workshop for undergraduate students was calculated from previous workshops at 80 Baht per meal for the estimated 30 students and staff at the workshop. There are two coffee breaks priced at 70 Baht per person.

The remaining two categories are materials and publicity. Materials cover the costs of chemicals, hand-outs, or other information packets during the workshop. Publicity includes mailing of posters and creating pamphlets to generate interest in attending the workshop. The miscellaneous costs account for any unforeseen expenses or errors in estimation into the budget.

Table 5.5. Sample Budget

Thailand Workshop Logistics Workshop: Proposed Undergraduate Student Green Chemistry Workshop Type of Workshop: Lecture and Laboratory Time: one day Accommodations: none - one day only Attendance: 30 Students $6,000 US dollars =approximately 240,000 baht	
Budget	
Income:	Baht
Registration	FREE
Income from outsource	240,000
Total	**240,000**
Expenses:	
People	
Payment for 1 day lecturer 3,000 baht/hr @ 3 people	40,000
Payment for laboratory assistants 300 Baht/hr - 3 assistants for 8 hours	7,200
International Fares for invited speakers from outside the region	130,000
Location	
Payment for Laboratory 1000 baht/hour - 1 labs for 7 hours	7,000
Payment for Lecture Hall @ 5,000 baht/day	5,000
Food	
Payment for lunch 80 baht/meal/person for 30 ppl	2,400
Payment for coffee break 70 baht/person/meal - 2 breaks, 30 ppl	4,200
Materials	
Materials and Chemicals	30,000
Publicity	
Pamphlets	2,000
Mailings	2,000
Miscellanous	10,200
Total	**240,000**
Income Total	
Expenses Total	**240,000**

Recommendation: Apply for the Green Chemistry Institute's Developing/Emerging Nations Grant located in Appendix 15 and apply to any other funding sources available at the time.

If awarded this grant, the workshop would be granted sufficient funding to be able to take place. Thailand meets all the requirements of this grant. Other sources of funding should be researched and applied for in the case that the application to the GCI-DEN Grant is not successful.

5.2.5. Publicity

Finding: Many methods of publicity have been successful for workshops in the past at Chulalongkorn University.

Publicity in the past has been successful through pamphlets, letters, flyers and emails and many more options. All of the workshops researched from Chulalongkorn University located in Appendix 11 have successfully communicated their workshop to the public through these methods. Many professors used pamphlets in workshops such as the Chitin and Chitosan workshop and the Small Scale Chemistry for High School Teacher's workshop. Email was also a useful tool because it costs virtually nothing and can reach a wide array of possible participants. Email is also useful when contacting people from other time zones.
From our Chulalongkorn University chemistry professor interviews, professor 9 stated, "Publicity was done by flyers, letters, emails, company also contributed a letter" while professor 1 stated that publicity was done through sending "application to their local school." Professor 3 states publicity for company sponsors was achieved through items such as banners.

Finding: Students are more likely to attend a workshop or seminar if the professor who suggested it to them shows personal interest.

Professor Julie Haack (2006) believes that it is important for professors to show personal interest in our proposed workshop by spending around 30 minutes of class time introducing green chemistry, and the workshop itself. This interview is located in Appendix 9. She reasoned that this will serve as an introduction to green chemistry for a large number of students, and get them interested in a green chemistry workshop. The importance of professor interest was also mentioned by Professor John Warner (2006) of the University of Massachusetts in his interview located in Appendix 8. He stated that when he recommends his students attend a workshop or seminar and expresses his personal interest by telling students he will also be there, a much higher percentage of students attend the event (Warner, 2006).

Recommendation: Use the logo, brochure, flyer, and website we have designed to promote the workshop.

Through our findings, we have designed a workshop flyer and brochure located in Appendix 20 that should be distributed to the chemistry departments of different universities in Bangkok, and factored these publicity needs into our sample budget. For additional online publicity, we designed a website announcement for a publication of the workshop. We concluded these would provide the best form for publicity because they are cheap and have been successful in the past at advertising Chulalongkorn University workshops. This publicity poses a limitation because we were only able to create the publicity items in English and we feel that it would give the greatest impact if they were translated into Thai.

5.3. Other Options – Age Groups and Lengths of Workshops

The purpose of providing a workshop is to generate interest in green chemistry and to act as the first phase of creating a green chemistry network in Thailand. In order to establish a green chemistry network, the action of a workshop in phase one can be adapted to other time lengths and age groups. These options are provided to assist with the continuous education of green chemistry and to generate new ideas such as providing outreach programs to younger students, summer workshops, and supplementary in depth workshops after the initial workshop we recommended in the previous sections of Chapter 5. The additional workshop options we provided are *age*, *length*, and *example laboratory experiments*. The different age groups are: *primary*, *secondary* and *undergraduate* students, while the different lengths of workshops are: *one day*, *two days* and *three days*. These options will be helpful in providing flexibility in the planning of other workshops.

This section illustrates the options for different types of workshops and offers a compilation of example laboratory exercises. The example labs are separated by the following age groups: primary, secondary and undergraduate students and are located in Appendices 17, 18 and 19 respectively.

Finding: Workshops for different age groups and different lengths require flexibility of options in schedule and laboratory activities.

This could be in place of our recommended workshop, or these options could be offered subsequent to an undergraduate workshop. The alternative workshops are also part of the first phase in establishing a green chemistry network.

We researched different types of workshops that all pertained to different audiences. We then provided an example layout of different age groups and lengths of workshops located in Table 5.6 below. Our previously discussed workshop logistics can be adapted to fit the needs of different age groups and different lengths of time.

Table 5.6. Layout of examples of different age groups and lengths of workshops

Age Group / Length	*Primary*	*Secondary*	*Undergraduate*
1 day	10 minute introduction to each laboratory 30 minute game time 1 lunch 2 laboratories 1 snack break 1 drink break	30 minute introduction 1 lunch 1 lecture 2 laboratories 2 breaks	30 minute introduction 1 lecture 1 lunch 2 laboratories 2 breaks
2 days	30 minute game time 10 minute introduction to each lab 3 laboratories 4 snack breaks 2 lunches 2 fun activities	Hands on building activity 30 minute introduction 1 lecture 3 laboratories 2 lunches 4 breaks	30 minute introduction 1 lecture 4 laboratories 2 lunches 4 breaks 1 problem solving lecture
3 days	Hands on building activity 10 minute introduction to each laboratory 4 short laboratories 3 lunches 6 snack breaks 3 games 3 fun activities	30 minute introduction each day 1 problem solving lecture with laboratory 3 laboratories 3 lunches 6 breaks 2 lectures	30 minute introduction each day 3 lunches 6 breaks 3 laboratories 1 project 2 lectures 1 problem solving activity

5.3.1. Primary Age Laboratories

Finding: Chemistry is not covered in the primary age group curriculum.

From our research of the National Science Education standards located in Appendix 21, chemistry is not offered in the primary age group curriculum. Since green chemistry is an advanced topic in the context of a chemistry curriculum, having a workshop for primary students would most likely be the first introduction they have had to chemistry, let alone green chemistry. We compiled examples of workshop laboratory activities located in Appendix 17. These examples are very simple chemistry experiments recommended for primary students and supplied by the American Chemical Society. Although not all of these laboratory activities involve green chemistry reactions directly, they can be modified to incorporate the meaning of green chemistry for primary students to understand. For example, the experiment titled “Colors on the Move” utilizes food coloring to distinguish between different types of milk. Green food coloring can be used during the experiment, then at the end of the experiment the lecturer can talk about the effects of green chemistry on food processing, such as milk.

5.3.2. Secondary and Undergraduate Laboratories

Finding: Green chemistry laboratory exercises are available for academic use.

The compilation of laboratory experiments for secondary and undergraduate curriculum came from sources such as the American Chemical Society Green Chemistry Institute and the laboratory book *Green Organic Chemistry – Strategies, Tools and Laboratory Experiments* by K.M. Doxsee and J.E. Hutchison. These reactions can be found in Appendices 18 and 19.

5.3.3. Length Options

Finding: 1, 2 and 3 day workshops are also effective workshop lengths for students to learn green chemistry.

We provided these options so that our sponsor may diversify her efforts to introduce green chemistry to students. These lengths were determined by the past workshops held by Chulalongkorn University chemistry professors located in Appendix 11.

5.4. Chapter Summary

These workshop logistic recommendations are limited to workshops held by Chulalongkorn University chemistry professors in the past. We did not research any other departments' workshops or expand our research scope beyond Chulalongkorn University. Being foreign to Thailand, we only have limited knowledge of the culture and the tradition in the way education is conducted.

In this chapter we first developed our recommendations for the optimal length and age group for a green chemistry workshop that will create the largest impact upon. We recommended this to be a one day undergraduate workshop. Following this, we recommended several workshop arrangements derived from our research of past workshops held by Chulalongkorn University chemistry professors. These recommendations included a small lecture portion and a large laboratory component in the workshop, a sample budget located in Table 5.5, publicity recommendations, and optimal number of students.

In addition to these recommendations, we also developed other workshop options that vary in age group and duration. We chose to provide other options so that our sponsor has the ability to organize various types of workshops in addition to our recommended workshop. An outline of these options was presented in Section 5.3. The workshops are detailed in Table 5.6. These workshop options are a part of the first phase in creating a green chemistry network in Thailand. We provided these recommendations and plans for the first phase to help ensure that it becomes a reality. We made these recommendations available to our sponsor in order to simplify the details when the workshop is run and to offer clarity in the future steps of creating a green chemistry network in Thailand.

6. CONCLUSIONS

The goal of this project was to provide recommendations for establishing a successful green chemistry network in Thailand and to design a workshop that would initiate this process. In order to achieve this goal we focused on three main research objectives. There were three main objectives involved in completing this goal. They were:

1) To determine common elements of successful networks that incorporate government, industry, and academia to promote environmental change.
2) To identify and recommend phases necessary in establishing a green chemistry network in Thailand.
3) To design a workshop which will contribute to the first phase of creating a green chemistry network in Thailand.

Through the completion of our objectives we identified several key findings. We recommended the phases and specific plan of actions that need to be taken in each phase in order to successfully establish a green chemistry network in Thailand. We also recommended a workshop as the next step in the first phase of this process.

The limitations of our project are important to consider. During our seven weeks in Thailand, we did not have adequate time to gain an understanding of the culture. Due to our lack of time, we did not fully comprehend the hierarchy in Thailand that is largely based on status of age, family, and job position. In making our recommendations every effort was made to take these differences into consideration.

6.1. Summary of Findings and Recommendations from Chapters 4 and 5

The findings and recommendations were split into two chapters. Chapter 4 illustrated the findings of the elements needed to develop a green chemistry network in Thailand and the recommended phases to be taken from these findings. Chapter 5 illustrated the findings and recommendations for a one day undergraduate workshop and also provided other options for different age groups and lengths of workshops.

There were six key elements found in existing successful networks. They are:

1) Communication
2) Education
3) Academia Involvement

4) Industrial Involvement
5) Government Involvement
6) Core Group of Leaders

From these findings, we proposed long term recommendations of phases to move through in order to successfully form a network. Within these phases we highlighted actions that can be taken by our sponsor so that these steps can be completed with clarity of purpose. The four phases are:

1) Expand interest in green chemistry
2) Create a core group of researchers
3) Reach out to industry
4) Gain support from government

We also provided the short term recommendations of logistics for the next action within the first phase which we defined as a one day workshop for undergraduate students held at Chulalongkorn University. We had several findings from this section. They were:

1) The past workshops held by educators have all had the common goal of increasing knowledge of the workshop's subject in students.
2) Interactive laboratories are the best way to maintain interest in the audience during workshops.
3) Small attendance workshops are more conducive to in-depth learning
4) The funding for this workshop can come from a number of different sources.
5) The sample budget for a one day workshop for undergraduates located in Table 5.7 is 6,000 United States dollars.
6) Use of pamphlets, letters, flyers and emails are a successful method of publicizing workshops at Chulalongkorn University.
7) Students are more likely to attend a workshop or seminar if the professor who suggested it to them shows personal interest.

From these findings, we made the following recommendations for the logistics of a one day undergraduate workshop:

1) We propose the following purpose of a one day green chemistry undergraduate workshop: To generate interest in undergraduate students in green chemistry by providing educational lectures and interactive laboratories.

2) A small lecture portion and a large laboratory component for the undergraduate student workshop.
3) The number of attendees for the undergraduate workshop on green chemistry should be 20 to 30 students.
4) Use the logo, brochure, flyer, and website we have designed to promote the workshop.

In addition to providing in depth example of the first action, we also gave information on different workshop lengths of one, two, and three days and different age categories of primary, secondary and undergraduate. These options can be applied to our recommendations of the one day workshop for undergraduates in Chapter 5. We also provided example green chemistry laboratories for all three age categories that can be used in future workshops. These laboratories are located in Appendices 17, 18, and 19.

6.2 Future Recommendations

In addition to the recommendations provided in Chapters 4 and 5 and summarized above, we also recommend future projects that can be derived from our project. These recommendations take into consideration other work that can be accomplished in the area of green chemistry in Thailand. Our long term recommendations range from having our sponsor form alliances with different networks that already exist to improving the green chemistry graduate program for Chulalongkorn University.

These recommendations are:

1) Green chemistry should be implemented at the undergraduate level at Chulalongkorn University. Given the professor interest we found, this recommendation can take place in two ways: green chemistry can be offered as an elective course or implemented in the existing laboratory and curriculum. A combination of both of these would be the best future option for increasing the education of undergraduate students at Chulalongkorn University.
2) We recommend that our sponsor collaborate with other existing environmental networks because we found numerous thriving networks that promote environmental change. To start a new network while forming an alliance with

these already successful networks will provide our sponsor with ideas that have succeeded, and establish contacts in government, education, and industry.

3) We recommend that our sponsor improves her relationship with the Green Chemistry Institute to use available resources. The Green Chemistry Institute has numerous experts and network advocates that can provide resources to our sponsor.
4) The improvement of Chulalongkorn University's green chemistry graduate program. To produce efficient green chemists, many of the students need more education in green chemistry to become experts.

6.3 Summary

By completing our goal, the outcome of this project is a workshop plan that our sponsor can hold within the next year, and a list of steps that she may follow after the workshop in order start a green chemistry network in Thailand. In addition, we recommended the long term goals of implementing green chemistry into Chulalongkorn University's undergraduate program, collaborating with existing networks that promote environmental change, improving relations with the Green Chemistry Institute, and expanding the graduate level green chemistry research conducted at Chulalongkorn University.

By creating a green chemistry network in Thailand, collaboration between industry, research, education, and government can help change the chemical industry's traditional methods of production and the pollution generated from these methods. It can potentially advance society to create a better environment while still providing economic benefits to industry in Thailand.

The chemical industry produces many benefits to society, however, often times harmful chemicals are used or produced in the process of manufacturing these beneficial products. Green chemistry provides a framework to break this cycle through strategic redesign of current traditional chemical processes. This enables chemists to manufacture these useful products without using or generating toxic substances. In turn, the economic, social and environmental benefits of green chemistry will improve the standard of living, and assist the continuing development of Thailand.

<u>References</u>

American Chemical Society. (2004). *Going Green: Integrating Green Chemistry into the Curriculum*. United States: American Chemical Society.

American Chemical Society Green Chemistry Institute. (2006). *2005 Green Chemistry Year in Review.* Retrieved January 30, 2006, from http://www.sitestories.com/gc2005yir/.

Anastas, P. T. (2006, Feb. 8). *Personal communication.*

Anastas, P. T.& Kirchhoff, M. M. (2002). Origins, current status, and future challenges of green chemistry. *Accounts of Chemical Research, 35,* 686-694.

Anastas, P. T. & Warner, J.C. (1998). *"Green Chemistry" Theory and Practice*. New York, NY: Oxford U P, Inc.

Anastas, P. T., & Williamson, T. C. (1998) *Green Chemistry Frontiers in Benign Chemical Synthese and Processes*; Oxford University Press: New York.

Bora, U., Chaudhuri, M. K., & Dehury, S. K. (2002, June). Green chemistry in Indian context – Challenges, mandates and chances of success. *Current Science, 82,* 1427-1436.

Brush, E. (2006, Feb. 8). *Personal communication.*

Chaianansutcharit, S. (2006, Jan. 31). *Personal communication.*

Chaisuwan, A. (2006, Feb. 9). *Personal communication.*

Coalition of Environmentally Responsible Economies. (2005). *Investors and Environmentalists for Sustainable Prosperity.* Retrieved February 2, 2006, from http://www.ceres.org/

Collins, T. (2001). Towards Sustainable Chemistry. *Science, 291, 5501,* 48-49.

Dementry, C. (2006, Jan. 12) *Personal communication.*

Eaton K.K., Anthony H.M., Birtwistle, S., Downing, D., Freed, D.L.J., McLaren, H.J., Maberly, D.J., Mansfield, J.R., Myhill, S. & Radcliffe, M.J. (2000). Multiple Chemical Sensitivity: Recognition and Management. A document on the health effects of everyday chemical exposures and their implications. *Journal of Nutritional & Environmental Medicine, 10*, 39-84.

Fischer, K. (2006, Feb. 3). *Personal communication.*

Fuangswasdi, S. (2006, Jan. 25). *Personal communication.*

Geiser, Kenneth. (2001). *Materials Matter: Toward a Sustainable Materials Policy.* Cambridge: Massachusetts Institute of Technology.

Green and Sustainable Chemistry Network. (2000). Retrieved January 23, 2006, from http://www.gscn.net/indexE.html

Green Chemistry Institute. (2006). *American Chemical Society*. Retrieved January 23, 2006 from http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=greenchemistryinstitute%5Cindex.html.

Green Chemistry Network: About GCN. *University of York*. Retrieved January 23, 2006 from http://www.chemsoc.org/networks/gcn/about.htm.

Greening of Industry Network. (2006). Retrieved January 23, 2006 from http://www.greeningofindustry.org/

Gurney, R. (2006, Jan. 20). *Personal communication.*

Haack, J. (2006, Feb. 3 & 24). *Personal communication.*

Haury D.L. & Rillero P. (1994). Perspectives of Hands-On Science Teaching. The ERIC Clearinghouse for Science, Mathematics, and Environmental Education: Ohio.

Hjeresen, D. L., Schutt, D. L., Boese, J. M. (2000, Dec.). Green chemistry and education. *Journal of Chemical Education, 77,* 1543-1547.

Hutchison, J.E. & Doxsee, K. M. (2004). *Green Organic Chemistry: Strategies, Tools, and Laboratory Experiments.* Australia: Thomson Learning, Inc.

Iwami, T. (2001). Economic development and environment in Southeast Asia: an introductory note. *International Journal of Science, 28*, 605-622.

Kamolsiripichaiporn, S. (2006, January, 27). *Personal Communication.*

Lancaster, Mike. (2002). *Green Chemistry: An Introductory Text.* Cambridge, UK: The Royal Society of Chemistry.

Murty, C. V. R., Dikshit, O., Tandon, R., Tandon, M. C., Jain, S. K. (2004, July). Recreating romance of civil engineering: 2001 summer camp at Indian Institute of Technology Kanpur, India. *Journal of Profesional Issues in Engineering Education and Practice, 130 (3),* 182-188.

National Research Center for Environmental and Hazardous Waste Management (NRC-EHWM). (2005). Retrieved January 30, 2006 from http://www.nrc-ehwm.chula.ac.th/default.htm

Nhujak, T. (2006, Feb. 8). *Personal communication.*

Nuntasri, D. (2006, Jan. 16). *Personal communication.*

Organization for Economic Co-Operation and Development. (2001).*OECD environmental outlook for the chemicals industry. Organization for economic co-operation and development environment directorate*. Paris, France: OECD.

Payne, A. C., deProphetis, W. A., Ellis, A. B., Derenne, T. G., Zenner, G. M., Crone, W. C. (2005, May). Communicating science to the public through a university-museum partnership. *Journal of Chemical Education, 82,* 743-750.

Pellerin, C. (2005, June). Chemistry goes green. *E-Journal USA: Global Issues.* Retrieved January 31, 2006, from http://usinfo.state.gov/journals/itgic/0605/ijge/pellerin.htm

Poliakoff, M., Fitzpatrick, J. M., Farren, T. R., & Anastas, P. T. (2002). Green Chemistry: Science and politics of change. *Science, 297,* 807-810.

Pulpoka, B. (2006, Jan. 17). *Personal communication.*

Singleton, R. A. Jr. & Straits, B. C. (2005). *Approaches to Social Research.* New York: Oxford U P.

Social Venture Network. (2003). Retrieved January 23, 2006, from http://www.svn.org/index.cfm

Sritana-anant, Y. (2006, Jan. 31). *Personal communication.*

Tangpasuthadol, V. (2006, Jan. 19). *Personal communication.*

Tantayanon, S. (2005, Nov. 20). *Personal communication.*

Tantayanon, S. (2006, Jan. 11). *Personal communication.*

The Greening of Industry Network: Research and policy for a sustainable future. (2006). Retrieved January 23, 2006, from http://www.greeningofindustry.org/.

Tyagarajan, K. The Global Chemical Industry-Looking up as Asia Leads. (2004). Retrieved 24 February 2006, from frost.com/prod/servlet/market-insight-top.pag?docid=10658071

Udomkanjananan, P. (2006, Feb. 7). *Personal communication*

Union Carbide Corporation. (2005, October). *Bhopal Information Center: Chronology.* Retrieved February 1, 2006, from www.bhopal.com/chrono.htm

United Nations. (2002). *Johannesburg Summit 2002: Thailand's Country Profile. Retrieved January 30, 2006, from http://www.un.org/esa/agenda21/natlinfo/wssd/thailand.pdf*

United Nations Department of Economic and Social Affairs: Division for Sustainable Development. (2005, Sept.). National Information: Thailand. Retrieved

November 19, 2005, from http://www.un.org/esa/agenda21/natlinfo/countr/thai/

U.S. Environmental Protection Agency. (2004, Oct.). *Presidential green chemistry challenge.* Retrieved November 11, 2005, from http://www.epa.gov/greenchemistry/presgcc.html

U.S. Environmental Protection Agency (2005, June). *The Presidential Green Chemistry Challenge Awards Program: Summary of 2005 Award Entries and Recipients.* Retrieved January 30, 2006 from http://www.epa.gov/greenchemistry/docs/award_entries_and_recipients2005.pdf

Vilaivan, T. (2006, Jan. 16). *Personal communication.*

Warner, J. (2006, Feb. 8). *Personal communication.*

Wicht, D. (2006, Feb. 8). *Personal communication.*

Zarworotho, M. (2006, Feb. 8). *Personal communication.*

APPENDIX 1: EMAIL/TELEPHONE INTERVIEW FOR GREEN CHEMISTRY EXPERTS

1. Have you ever run a workshop or seminar before?
    a. If so, what did it entail? Who was it for? How were they chosen to attend? What programs were offered? How long did it last? How did you fund it? Who ran it?
    b. How do you think a workshop would differ based on the population it is aimed at? Students vs. professors?
2. Do you think a workshop or seminar aimed specifically at students would be a strong starting place for green chemistry at a University?
    a. If not, what would you suggest?
3. What do you feel the benefits would be of having a workshop or seminar initiated first versus introducing green chemistry in the classroom first?
4. Have you ever changed a part of the curriculum that you teach at your university?
5. Have you ever been a part of a movement to change how something was taught?
6. If yes to either above, what were the steps that you needed to go through to make the change?
    a. Were they difficult to move through?
    b. What administrative levels exist?

APPENDIX 2: CHEMISTRY PROFESSOR INTERVIEW AT CHULALONGKORN UNIVERSITY

1. What do you know about green chemistry?
2. Where or who did you learn about green chemistry from?
3. Do you think it is a beneficial aspect to our society?
4. Do you think it applies to students? Or do you feel that it is not necessary to learn it at an early age but to learn about it in practice in industry?
5. Would you like to see Chulalongkorn University have a green chemistry program? Or a class on green chemistry?
6. If you feel that green chemistry should be a part of the University curriculum, how do you foresee the future of green chemistry here?
7. Do you think that Chulalongkorn University could become the forefront of green chemistry research in Thailand in the future?
8. Do you think students would be interested in this?
9. Do you think a workshop or seminar aimed specifically at students would be a strong starting place for green chemistry at Chulalongkorn University?
    a. If not, what would you suggest?
10. If you feel that green chemistry in the curriculum would not benefit the University, do you think that a workshop for secondary and undergraduate students would still be beneficial?
11. Have you ever changed a part of the curriculum that you teach here?
12. Have you ever been a part of a movement to change how something was taught?
13. If yes to either above, what were the steps that you needed to go through to make the change?
    a. Were they difficult to move through?
    b. What administrative levels exist at Chulalongkorn University?
14. Have you ever run a workshop or seminar before?
    a. If so, what did it entail? Who was it for? How were they chosen to attend? What programs were offered? How long did it last? How did you fund it? Who ran it?

APPENDIX 3: NETWORK FOUNDER INTERVIEW

1. What is the primary goal of your organization?
2. What is the future vision of your organization?
3. How was your organization established?
4. What were the first steps in establishing your organization?
5. How do you currently expand your network contacts?
6. Who is currently in your network?
7. Do you hold workshops or travel to various places?
8. How do you receive funding?

APPENDIX 4: ANALYSIS OF CHULALONGKORN UNIVERSITY CHEMISTRY PROFESSOR INTERVIEWS

Appendix 4.1: General Table Used

Professor	Response
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Appendix 4.2: Professors' feelings and knowledge with respects to green chemistry.

Appendix 4.2.1: Responses to: Questions 1 & 2, Appendix 2

Professor	Response
1	• Has known about green chemistry for 5 years, since studied for PhD, thesis was related to green chemistry because professor worked with it
2	• Familiar with green chemistry. First heard from Dr. Supawan, has seen some journals on green chemistry, and has seen many industrial processes
3	• Learned about green chemistry at a workshop for Professors at Chulalongkorn ▪ Learned a little more from Dr. Duangamol ▪ Wants to learn more about green chemistry • Polymer Chitin from crab tail, he does lab work in aqueous solutions
4	• Knows of green chemistry, particularly knowledgeable on alternative solvent reactions • First read of green chemistry "a while ago" in a science journal
5	• She does not know very much, only that it is environmentally friendly • First heard about it here at Chulalongkorn • Also heard about green chemistry at a seminar for Professors on micro-scale labs
6	• Knows a little, read about it at first • Coming to the spotlight more and more • Actually, only the name green chemistry is new, old practice of trying to run reactions safely Read about it first
7	• She doesn't know about green chemistry, although her area of interest is in environmentally related research ▪ Knows that green chemistry is related to environment, but doesn't understand the reason for the term green chemistry • First heard of green chemistry from Dr. Supawan • Would go to a seminar to learn more
8	• Didn't attend John Warner's seminar but yes I know about green chemistry- I know about the principles… 8 or something. • Yes, I learned about it five years ago. It started from when I joined Dr. Supawan for students to reduce chemistry waste in laboratories. It was small scale lab. It originated from how to work safely in the lab. Then I read about green chemistry in books and several other places.
9	• It involves technology and techniques that produces less waste. • I learned from some professors at Chulalongkorn.
10	• Industry does not use it, they cannot do real green chemistry in real life because they are producing carcinogens, but are trying to do it • Think about how to manage waste better • From professor Takashi Tatsumi – was at another university first, member of the Japanese organization with green chemistry and tried to advertise it, has same ideas as hers

Appendix 4.2.2: Responses to: Question 3, Appendix 2

Professor	Response
1	• Helps environment • Can help to make a better life for Thailand and the world
2	• Yes, thinks will be more important in a few years
3	• Of course, reduce waste: in=out • Thinks green chemistry is beneficial in many ways ▪ Seems to know the basics of green chemistry ▪ Deriving green reaction substitutions requires time and money, this hinders university use
4	• Everyone can benefit from green chemistry • Green chemistry cannot be applied to every reaction • Both industries and universities have to incorporate green chemistry little by little
5	• Thinks that green chemistry is beneficial to society • Green chemistry should be in universities first, rather than industry •
6	• Human nature to be concerned about surroundings • To emphasize green chemistry, it to remind chemists that they are responsible for environment • They cannot just put environment as the last priority • Shows that people actually care • If people realize the aim of GREEN CHEMISTRY, then yes he thinks it is beneficial
7	• Yes
8	• *non-response*
9	• I think it is good to do green chemistry, I am not sure about the profit. So maybe we have to invest money to do green chemistry.
10	• if they can really do it, then it is benefical to society; if only think about green chemistry then may lose some products; with their project try to teach students about safety of world, but if product does not work what do in real life, so have to tell them both ways –but have to do one way because doesn't work with green chemistry way • yield is much better with toxic chemical as solvent much higher yield, when use H2O2, get a .8% yield, with toxic get about 30%

Appendix 4.3: Student interest in green chemistry

Appendix 4.3.1: Responses to: Question 4, Appendix 2

Professor	Response
1	• Believes it is necessary for University students to learn green chemistry before entering industry • Students who know green chemistry in University will take it to industry o Universities should be the center for green chemistry and industries will adopt it
2	• Believes that green chemistry should be introduced in Universities, maybe introduction lab courses o Should account for 10 or 20 percent of total class time • Some chemistry should be traditional however
3	• Yes, good idea.
4	• It is important and necessary for undergraduate students to learn about green chemistry ▪ Students can help develop greener reactions for industrial application
5	• Small scale labs-good for qualitative illustration but not quantitative evaluation • Small scale labs more applicable for 1st years students
6	• Green chemistry should be added into other classes ▪ Incorporated overall ▪ Adds responsibility to each class
7	• *Unaware of meaning of green chemistry*
8	• Yes, I think it does.
9	• I think they should learn it at Chulalongkorn University.
10	• does not expect this, because it is just an ideal system, not real life, once students learn this will laugh at you because can't apply it

Appendix 4.3.2: Responses to: Questions 5, 6, 7, Appendix 2

Professor	Response

1	• Taught a graduate green chemistry course and would like to teach undergraduate level green chemistry course but hasn't had the chance yet
	• She does not feel that green chemistry can be an undergraduate major, but believes that green practices should be incorporated into undergraduate labs
	  ▪ Expanding the green chemistry graduate program is a good idea
	  ▪ Thinks should be a part of each class
	  ▪ More possible to have a PhD in GREEN CHEMISTRY, but not an undergraduate major
	• Thinks university should be center of GREEN CHEMISTRY and then should spread to industry

2	• He is interested in applying more green chemistry in labs
	  o Some reactions need to be left traditional
	  o Greening of every reaction is not possible
	• Would make an interesting elective course
	• Feels 2nd year students are too young to really understand it
	• Undergraduate courses should teach green chemistry
	  o Some green chemistry is already in use in undergraduate labs at Chulalongkorn
	  o Dichromium replacement with nitric acid
	  o Students understand that this is green replacement
	  o Feels that a green chemistry course should be for 4^{th} year students

3	• Would like to see more green chemistry being used at Chulalongkorn
	  ▪ Should be incorporated into curriculum (normal courses) rather than an elective course
	  ▪ Easiest way to practice green chemistry is micro-scale chemistry
	  ▪ Need more staff
	• Would green chemistry work at Chulalongkorn
	  ▪ Believes that someone should create green research group at Chulalongkorn
	  ▪ Currently, 10 research group exist, he is same group as Dr. Supawan
	  ▪ Dr. Supawan wants to change from "polymer" research group to "green chemistry" research group
	  ▪ He would be willing to change to green chemistry research group
	  ▪ Feels that if have a workshop, the excitement/idea will fade away after a period of time
	• Says best way to increase awareness would be to say they are doing green reactions with the ones already are doing – that way names would stick. right now aren't saying they are green.

Appendix 4.3.2:Contindued

Professor	**Response**
4	• Necessary to have a course offering in green chemistry ▪ Green chemistry is useful, a new trend and an emerging field ▪ Students should learn about the benefits and limits of green chemistry ▪ Would most likely be offered as an elective course ▪ Some students (undergrads) will have heard of green chemistry, will not know details or much about theory. ▪ Students should learn how to "think green" in designing reactions ▪ Green chemistry undergraduate course should be for 4^{th} year students
5	• There should be an elective course in green chemistry offered at Chulalongkorn
6	• Should be blended into current courses, be integral • Rather than separate class • Understands that green chem. is not a separate entity • Doesn't want to see it separated • Requirement for lab student to go through safety course, green chemistry could be put into this because it doesn't teach anything about environment relation • Not as applied if a separate elective course, because then saying only need to take responsibility for actions if take the course • Doesn't want GREEN CHEMISTRY as is own unit, should be integrated into other fields.
7	• *Did not understand meaning of green chemistry*
8	• I think a Green chemistry elective course is a must. It should be an elective but we must have it. Because you have to put it in your mind when you do everything and think about the safety and the waste, you can do everything in your kitchen at home. • I think an undergraduate course would be the best. It is a must. • Yes.
9	• I think we don't have the program, I heard maybe a few professors in the department do research in green chemistry. Maybe the first step could be a seminar or a short course. • I think we have one graduate green chemistry course. Green chemistry could be an elective. Undergraduates should learn about green chemistry. • Yes.
10	• does not expect this, because it is just an ideal system, not real life, once students learn this will laugh at you because can't apply it

4.3.3. Responses to: Question 8, Appendix 2

Professor	Response
1	• She talked about what is right/necessary for students to know. • Feels that necessary for university students to know so that they can suggest the idea to their boss. It doesn't matter whether he accepts the idea or not, but at least it will be planted there.
2	• *non-response – needed to go to class*
3	• They might not know what it is • There should be a campaign to raise awareness
4	• Thinks students want to learn green chemistry • Students want to know what happens in industry in real life.
5	• Students are generally interested in helping the environment • Has not spoken to students about green chemistry
6	• Catchy name… • Then it depends on the professor • They will think green chemistry is interesting – initial learning is interesting, but afterwards depends on professor
7	• *Did not understand the meaning of green chemistry*
8	• Yes, they could read about it in any chemistry book. Even if you write a lab manual or the chemistry textbook, you can put something like the precaution or harm how to use it wisely and safely in the book everywhere. You can create that without cost. Or even ask how to get rid of this, how to handle this along the way so they think about it. Even not green chemistry book, any chemistry book.
9	• Some of them because in chemistry if you have a variety of subject and green chemistry is one of the courses maybe some of them will have interest.
10	• Every year have to announce their research topics for new students; when Dr. Duangamol offered to do research on green chemistry she did not get any undergraduate students offer to help her; they did not know what it was, but some might know; they do not only think about research but about how they can get work after graduation so want to work with ex. fuel so will get hired

4.3.4.Responses to: Question 9, Appendix 2

Professor	**Response**
1	• Agrees that a workshop is a good starting place for green chemistry at Chulalongkorn
2	• *non-response – needed to go to class*
3	• A good idea • Even some Professors are unsure about what green chemistry is

4	• It is important to provide a basic break down of green chemistry
	• Effectiveness of workshop will depend on contents
	  • Essential that workshop be interesting, fun, funny, not too hard
	• Compare and contrast traditional and green chemistry
	• Is green chemistry appealing to students?
	  ▪ Depends on intended outcome of workshop
	  ▪ Highlight all of the benefits of green chemistry, saves energy, waste, etc

5	• Should also be offered to high school students, and non-Chulalongkorn students
6	• Good idea.
7	• *Did not understand the meaning of green chemistry*
8	• Yes.
9	• Yes, but you should start with the graduate students.
10	• somehow, not all graduate students graduated from here, so good for them, so teach them about the research; • thinks good so when go to work will have something to remind them that they need to benefit world and not just themselves

Appendix 4.3.5: Responses to: Question 10, Appendix 2

-Only professor 10 had qualms about green chemistry in the curriculum, although she did feel students should know a little about it, she only felt that green chemistry should not be integrated into every course. All felt a workshop would be beneficial.

Appendix 4.4: Changing curriculum – *Responses to: Questions 11, 12, 13, Appendix 2*

Professor	**Response**
1	• 10 labs are required, she has authority over 3 of them • She can set her own three labs…this is for 4th year students. • 4th year students have a senior project
2	• Professors are not prohibited from adding material to the courses they instruct o Revise syllabus and submit to committee, usually it is not too hard to get committee approval o Creating a graduate course is easy o Setting up a new undergraduate course tougher, usually ends up being an elective o There is a committee at the faculty level and at the university level
3	• Changes he made were small and incremental. They were mostly "updates" rather than real changes in content • To change topic list, department approval is required and is not very difficult to get • Easy to do, but time consuming • No experience with large changes to curriculum
4	• Dr. Buncha has never changed anything in a university curriculum
5	• Elective courses are easy to create ▪ She has not done it ▪ Department divided into 4 divisions, is specific division agrees, then it is pretty easy ▪ Has taught selective topics at undergraduate level
6	• Mostly, old curriculum is modified. Information gathered from various professors, no specific or central core information. Can be hard because of the many different backgrounds of profs • Undergraduate-electives are created because people with interest or a lot of knowledge on a particular topic usually encourage the creation of course
7	• Aqueous chemistry, waste minimization • Added this material into course, it was a special topics grad course • Has not made changes in undergraduate courses • teaches basic organic which has established guidelines to follow
8	• *non-response*
9	• No, but I would like to for the future. It takes time to prepare things

Appendix 4.4: Continued

Professor	Response
10	• Regularly update course, improve it to catch up to world – but concept is still the same • She is on exec board • Need to modify program every four years to update, if not good will change syllabus, if ok then don't touch it – for that purpose all staff go to big meeting and they do this every year in summer for 2 or 3 days, once everyone agrees responsible team collects info and comments and adjusts it and shows at last hour of meeting; to do like this don't need board • Have 75 teaching staff in chemistry

Appendix 4.5: Workshop challenges – *Responses to: Question 14, Appendix 2*

Professor	Response
1	• Developed curriculum for a camp for Junior High students about green science • She lectured on green chemistry • Lecture content was not too detailed and was only intended to give students the general idea • Students submitted applications to their local school, then schools sent applications to the camp • This camp was free, however funding was inadequate to allow the camp to run a second year despite high student interest • The camp took place March 23, 2002 • Camp was funded by a government grant • Better to do camp over 2 days, no overnight • Size of workshop is limited by the depth of information, lecture only lectures can be for large audience, labs require smaller size
2	• Feels that a workshop for young students is a good approach for sparking student interest in green chemistry o Younger than university age is best o Increase public understanding, help to get rid of view of chemistry as a dirty science o One or two day workshop is good amount of time o Workshop should be interactive o Idea of workshop for younger students a new idea at Chulalongkorn o Length – 1 or 2 days if want to do hands-on-things
3	• International polymer conference 2003, Chulalongkorn and Mahidon University in conjunction 500 people. • He was on the organizing committee • Held at conference center in Bangkok • Financed by • the universities, a registration fee and sponsorship from Thai companies o 10 percent from companies • Proposed levels for funding, each level earned the sponsor more promotional items such as company logos, banners, etc.
4	• Yes, on how to write proposals and conducting research…not chemistry related • Bioactivities of natural products, 5 years ago, seminar plus1 or 2 days of workshop activities
5	• 8th floor would be best, they deal with organic chemistry • Total of 8 “wings” that have 50 benches each • Workshop should include both lecture and hands-on activities • Students at Chula might already have a basic idea of what green chemistry

Appendix 4.5: Continued

Professor	Response
6	• Not for students • Ran one for academics • Appropriate for undergraduate, maybe not for younger students • For younger students, harder to keep interest, has to be more like a play than actually learning • 1 day or two days for undergraduate level • Have to focus it not as boring • Timing is right, then it will work • Summer might be good, start of semester, semester break • Possible to use a lecture to do green chemistry workshop instead. But, difficult to convince professors and hard to pull it off-but possible
7	• No • 1 or 2 days would be OK
8	• Yes b.If so, what did it entail? Who was it for? How were they chosen to attend? Two day workshop, it doesn't matter. Length for student workshop – I have never tried really workshop for students except introduce teaching them by small scale chemistry I have never done green chemistry but use small scale chemistry to teach them in the subject. Normally I set up the workshop for the teachers. Workshops put on for high school teachers how to make labs small scale labs. Not a green chemistry workshop. I would like to introduce a small scale chemistry teaching in school. From my interest there are three aspects: small scale chemistry to reduce waste in chemistry lab in university. General chemistry. I create some manual for the high school lab to integrate lab into classroom. I use another aspect of small scale lab and convenient to do everywhere. In the high school and research. Small scale for analytic chemistry is very handy, fast and informative. I used the advantage of the small scale in high school but not green chemistry. But I can put in ideas of green chemistry into this small scale manual into high school. I do workshop every year if I have financial support. Maybe I didn't get the principle of green chemistry like you have in mind. Maybe the principle that I have in my mind is different than yours. The way I'm doing it is green education. I try to avoid, you don't have to learn by the toxic waste. I try to set the concept about the safe way to make chemicals. Says yes, she tries to reduce toxic chemicals by changing starting chemicals. The last workshop was in probably May 2005. We have the last one about 200 teachers in March. About 50 high school teachers in May 2005. The ministry of science and technology is where we receive funding. Sometimes it is from organizations. This year we try to get companies and private sectors. Petroluem of Thailand is in negotiation. 6 million baht a year. 5 consecutive years. Maybe I have something between May, in Rayong Providence funding from NPC – National Petroleum Council (a company) for 40 high school teachers.

		Lab manual and another small book for the teachers on the 15th floor. We also have a manual for 1st year students. b. What programs were offered? How long did it last? How did you fund it? Who ran it? Workshops are two full days. Format is hands on in a big lecture room with tables anywhere. Sometimes it is in the cafeteria. I bring in all the stuff and set up. I try to get to the principle of small scale chemistry and what they can learn from the design lab. I try to talk about what is in my mind, why I decide that lab. They can learn and design by themselves later. Sometimes 1 day. Like in Rayong providence. We always do it during the summer school break (march-may) and October one month break. Application process is by sending leaflet to the school and asks them to send someone. It is free. Everything is free. Like I talk to Prof. Thompson I join him for three weeks several years ago to see how he runs the science center over there about small scale chemistry lab too. He said it would be okay with free lunch. But I can take that moment to impress them. It works very effectively. Some teachers never see anything like that. c. Determining budget is from lab manual, I have how much chemicals I have to use. We sent up the starter kit for the small scale lab. I know the price and the chemical I use, we will set up, and we will put the chemicals into pipette and send to them. We know how much a start kit is. After the workshop, this will be given to them… its about the start kit to do every experiment. There are 21 reactions. They can order one and it's not just for profit, its easy to use. The chemicals in each lab will be in small plastic 0.1 molar of chemicals, they don't have to buy anything. It is sent by post mail. This is given (the packet) to everyone who attends the workshop. They don't have the lab technician or staff so it is easier for them to buy it from us. d. Chemical pricing, we are just accustomed to it and I don't know the exact rate. We have the price and can calculate the price plus the price of containers. My helper does the ordering. I pay her money to buy, she is on the 9th floor. We have a price list according to the company, we order by the storeroom. The storeroom is in charge of ordering chemicals and some people working in it. The professor who orders it is Dr. Pologrit. The storeroom is in the building Chemistry 1.

Appendix 4.5: Continued

Professor	Response
9	• It was at Chulalongkorn University. 50 people. Gie some lectures and laboratory (demonstration). Lecture was four hours. The whole workshop was a full day. Some had to apply and some we invited. They applied by email. In the email they just stated they wanted to join. Got funding for the company from Beckman Coulter and PCL holding Company. Asked for 30,000 baht. It was held last year in December 2004. I knew a personal contact at the companies. Publicity was done by flyers, letters, emails, company also contributed a letter – they wanted some research • Capillary electrophoresis, for graduate and researchers in thaialdn, here, 50, lecture and lab demonstration, 4 hr lecture and another 2 for demonstration, one day, some had to apply and some he invited, applied by email to say wanted to join, funding from company –Beckman Coulter (PCL Holding Company), 30,000baht, food 60 per person, December '04, made personal contact to get funding,
10	• Have a grant for Japan Bank for International cooperation to buy instruments so she needs to run workshops as a part of this – have about 5 visitors a year. when get new instrument need to show everyone how to use it, so many people may come and will need to make more than one day. • Workshop usually half a day or one day, sometimes demonstrations, lectures, for undergraduates and graduates, most audience are graduate students though What she often hears with green chemistry people is that in the beginning they are very interested such as in a workshop, but at end they say so what where are you going to use this, it can't work everywhere; sometimes graduate committee asks students about this, asks why so interested in green chemistry, if it doesn't' work, how can you make something with it

APPENDIX 5: NETWORK ARCHIVAL RESEARCH ANALYSIS

Appendix 5.1: Network and Location

Network	Location
1. Greening of Industry Network	Global: Europe, N. America, Asia
2. Green Chemistry Network	UK: University of York
3. Green Chemistry Institute	USA, global chapters
4. Ceres	Global
5. Green and Sustainable Chemistry Network (GSCN)	Japan
6. Social Venture Network (SVN)	USA
7. National Research Center for Environmental and Hazardous Waste Management (NRC-EHWM)	Thailand

Appendix 5.2: Network goal and future vision

Network	Research
1	Mission *The Greening of Industry Network develops knowledge and transforms practice to accelerate progress toward a sustainable society.* Vision The Network seeks to create new concepts and a new language that will make it possible to extend our horizons and communicate across disciplines, nations, and sectors.
2	The main aim of the GCN is to promote awareness and facilitate education, training and practice of Green Chemistry in industry, commerce, academia and schools. The Green Chemistry Network aims to help these chemical companies and chemists by sharing best practice, promoting green technology transfer and providing data to show that adoption of green practices can also provide cost benefits for industry. In addition, we aim to make it possible for chemists of the future to grow up in an environment where green issues are not taught in isolation but form the underlying principles of all courses.
3	Mission: The mission of the Green Chemistry Institute (GCI) is to advance the implementation of green chemistry principles into all aspects of the chemical enterprise.
4	Mission: Ceres' mission is to move businesses, capital, and markets to advance lasting prosperity by valuing the health of the planet and its people. Core beliefs: Ceres works closely with a select group of companies that have made public commitments to stakeholder engagement, public disclosure, and performance improvements. The 85-member Ceres coalition and our 70-plus partner companies share these core beliefs: ▪ environmental stewardship and company value are strongly linked; ▪ the bedrock of sound corporate governance is measurement and disclosure; ▪ responsible companies must provide their investors and stakeholders complete and transparent information about their environmental performance.
5	Mission: The main mission of the GSCN is to promote R&D on Green & Sustainable Chemistry as a center of network, through such activities as promotion of collaboration including international activities, information exchange, communication, education and relevant proposals to funding agencies.

Appendix 5.2: Continued

Network	Research
6	Mission: SVN's mission is to inspire a community of business and social leaders to build a just economy and sustainable planet. Too much of today's business and economic activity operates at the expense of our biosphere and future generations. We believe in a new bottom line for business, one that values healthy communities and the human spirit as well as high returns. SVN members are a part of an expanding global network of pioneering entrepreneurs who share this vision and are helping to transform the way the world does business.
7	National Research Center on Environmental and Hazardous Waste Management (NRC-EHMW) has two main objectives; one is the development of a center of excellence to be a forum for environmental scientists and engineers to conduct research and develop new technologies. While the other is the establishment of quality post-graduate programs to produce qualified graduates to serve industry. It is envisioned as a research consortium of excellence that pools resources from universities, government and industry to integrate ideas, expertise and technology transfer. Participation of these components will be essential for a complete embodiment of dedicated researchers, excellent equipment and sufficient funding to solve well defined problems.

Appendix 5.3: The start of the network and how it was established

Network	Research
1	Since 1991 The Greening of Industry Network is an international association of researchers, business leaders, activists, and policy makers dedicated to building a sustainable future. With coordinating offices in the Netherlands, Thailand, and the United States, we engage participants from more than 50 countries to respond to the challenge of sustainable development. Through linked conferences, publications and communications, the Network creates new relationships, visions, and practices for sustainability.
2	The Green Chemistry Network was launched by the Royal Society of Chemistry and is based within the Department of Chemistry at the University of York.
3	History: After more than a year of planning by individuals from industry, government and academia, the Green Chemistry Institute (GCI) was incorporated in 1997 as a not-for-profit 501(c)3 corporation devoted to promoting and advancing green chemistry. In January 2001, GCI joined the American Chemical Society (ACS) in an increased effort to address global issues at the intersection of chemistry and the environment. From its earliest days, the Green Chemistry Institute (GCI) has sought to be the premier change agent that has the knowledge, expertise, and capabilities to catalyze the movement of the chemical enterprise toward sustainability through the application of green chemistry principles. To fulfill its mission, GCI supports research, works to integrate green chemistry into all levels of chemical education, aides companies with industrial implementation, hosts conferences, and coordinates efforts with an international network of green chemistry advocates.
4	History: Ceres was formed in 1989 as a groundbreaking partnership between leading environmental groups and institutional investors. Ceres emerged just as the Exxon Valdez oil spill in Alaska motivated the environmental and investor communities to push for higher standards of corporate environmental performance and disclosure. That work resulted in the creation of the Ceres Principles, a pioneering 10-point code of corporate environmental conduct that has led to the widespread adoption of environmental principles by companies worldwide. In 1997, Ceres launched the Global Reporting Initiative (GRI), which has now become the de-facto international standard for corporate reporting on economic, social and environmental performance. Since 2002, GRI has been an independent institution. Today over 700 companies from around the world use the GRI reporting guidelines. In 2002, Ceres launched the Sustainable Governance Project to raise global climate change and other emerging sustainability issues as significant risks that must be addressed by corporate boards and investment fiduciaries.

Appendix 5.3: Continued

Network	Research
5	Background: The Green Chemistry(GC) Initiative, a task force consisting of representatives from Japanese chemical organizations, was formed in September 1998. It worked actively to implement practical methods of effectively pursuing the above goals. To this end, a workshop was held in Tokyo in November 1999. The participants agreed to establish a new organization, Green & Sustainable Chemistry Network(GSCN) and the official name, concept, structure and framework of the activities by this new organization. Launching of GSCN: The Green & Sustainable Chemistry Network(GSCN) was officially launched in March 2000.
6	History: Founded in 1987 by some of the nation's most visionary leaders in socially responsible entrepreneurship and investment, Social Venture Network (SVN) is a nonprofit network committed to building a just and sustainable world through business. Founded in 1987, SVN is a community of leaders-company founders, private investors, social entrepreneurs and key influencers-who share a commitment to building a just and sustainable world through business. The relationships and initiatives born within our network have ranged from lasting friendships to investment deals to founding organizations to political action.
7	Chulalongkorn University, together with four other universities – namely, Chiang Mai University, Khon Kaen University, King Mongkut's University of Technology Thonburi, and Prince of Songkla University 0 proposed to set up a NRC-EHWM. The Research Center was established under the Ministry of University Affairs' Higher Education Development Project, with its goal to strengthen academic capability, R&D, and human resource development. A major portion of its financial support has been obtained through a loan from the Asian Development Bank and the government budget, starting from 1999.

Appendix 5.4: Who is involved in the network and how it has expanded

Network	Research
1	Who: The Network is an international association open to all who are interested in the sustainability challenge, the intertwined issues of industry, environment and society. We work in research, education, business, civil society organizations, consultancies and government, representing over 50 countries. Our Work: The Greening of Industry Network stimulates, coordinates and connects high quality research to policies, strategies and actions in ways that contribute to a more sustainable society. Through a variety of arenas, we provide an open forum for creative debate to engage researchers, business, workers, government, consumers and other actors in developing a shared understanding of the changes required for creating a more sustainable future.
2	Advisory board, industries, universities (formed through University of York, UK), government
3	Staff: The members of GCI staff come from diverse backgrounds and experiences, but share the conviction that green chemistry is a fundamental building block in the efforts to create a sustainable economy. We pursue GCI's mission in an entrepreneurial atmosphere in which individual creativity is supported and enhanced by a foundation of strong teamwork. The members of the GCI Governing Board are drawn from government, industry, academia and national laboratories to reflect a broad set of environmental interests and capabilities. The 23 Green Chemistry Institute international chapters are all at various stages of development. The number of green chemistry related affiliations and programs increase with the number of years since chapter inception. All the reporting international chapters have participated in green chemistry education, whether it is hosting events, publishing materials (including online), or increasing their own knowledge of green chemistry. Over 30 green chemistry education programs were reported. There are 33 green chemistry educational materials available in association with the international chapters, yet every chapter reporting a critical need cited educational materials and training opportunities.
4	Ceres is a coalition of over 80 investor, environmental and public interest organizations united to advance corporate responsibility. Ceres coalition members come from a diverse range of organizations, including Trillium Asset Management, Union of Concerned Scientists and AFL-CIO.
5	Members involved from each of main three sectors; also exist a number of boards and smaller groups within the network

Appendix 5.4: Continued

Network	**Research**
6	SVN is a peer-to-peer network which means that our members are CEO's, founders and senior executives of some of the most progressive companies in the world. Our members believe that today's dominant and economic paradigm promotes ever expanding economic disparity and ever increasing resource extraction and consumption at the expense of the earth and future generations. As a learning community we realize the unique challenges facing entrepreneurs and investors who want to leverage business for a more just and sustainable world. We actively recruit new members who are willing to engage in honest dialogue as we strive for continuous improvement.
7	The NRC-EHWM main center is located at Chulalongkorn University which is nominated as lead university while its four satellite centers are established at consortium universities in Bangkok and all regions of Thailand, such as Chiang Mai, Khon Kaen and Songkla province. The Administrative Office which is known as SPIU (Sub Project Implementation Unit) is settled at Chulalongkorn University in Bangkok. The SPIU of the lead university will cooperate with the Co-Principle Investigators of the satellite centers in each region to operate the academic and research affairs of the Center. With the collaboration by means of network between the Center and its satellites, the environmental problems in each region will be promptly addressed. In addition, an autonomous administration will be adopted to facilitate flexibility in the operation in order to maximize the productive outcome and its sustainability. All university members strongly support the Center and will provide leveraged funding to accelerate the growth of the Center.

Appendix 5.5: Main Activities

Network	Research
1	The Network's core activities are linked meetings, publications and communications. Through our publication series, we extend the reach of the research and dialogue of our convenings. Contributors to the series include researchers, business strategists and government policy makers.
2	Education: This page provides a list of useful information on Green Chemistry issues of possible use in undergraduate, A-level and GCSE courses. The GCN is building up a database of primary education resources and may be able to provide more information; industry: This page provides a list of useful information on Green Chemistry issues of possible use in undergraduate, A-level and GCSE courses. The Green Chemistry and the Consumer project is an exciting new venture from the GCN, aimed at delivering knowledge and understanding of Green Chemistry to consumers and retailers, and covers all chemical-dependant consumer products including clothing, furnishing, electronic goods, personal care products and food. The project also aims to engage representatives from throughout the entire supply chain and to encourage direct involvement of the retail trade in green chemistry research. Marks and Spencer, the Royal Society of Chemistry and GlaxoSmithKline have all now agreed to fund the project for the forthcoming year. One of the main outputs from the project will be a quarterly newsletter (see below), which describes current greener chemical information in a way that is comprehensible to a widely non-technical audience. Readers will be informed of recent advances in chemistry applicable to greener chemical products, implications of relevant legislation will be explained in a more understandable manner and other related topics, such as Green Chemistry research opportunities, will be communicated. The GCN is holding annual events in connection with this theme, which are also targeted at relevant trade associations, academics and industrialists. See below for presentations from the workshops. There are also plans to develop a dedicated website to support the newsletter and act as a technology brokerage facility, as well as initiating an awards programme for Greener Consumer Products.

Appendix 5.5: Continued

Network	Research
3	One of the goals of the Green Chemistry Institute is to recognize outstanding contributions in green chemistry in an effort to increase implementation of green chemistry technologies. Awards programs are highly visible mechanisms for informing chemists and society at large about the benefits of green chemistry. Presidential Green Chemistry Challenge Awards Joseph Breen Awards Kenneth G. Hancock Memorial Award Education: GCI's educational emphasis is on increasing awareness and understanding of Green Chemistry principles, alternatives, practices, and their benefits within traditional educational institutions, and among practicing chemists and other scientists. Educational Resources by Grade Level research: A primary objective of GCI is to advance research in Green Chemistry by promoting funding, increasing opportunities, and developing information on the benefits of green chemistry. Our efforts span the spectrum from theory and basic research through application and commercialization of science and technology. GCI also sponsors a number of research fellowships and scientific exchanges Industrial Implementation: The Green Chemistry Institute uses its expertise, capabilities, and experience to catalyze the movement of industrial enterprises toward sustainability through the application of green chemistry & engineering principles. Why Green Chemistry & Engineering? Green Chemistry and Engineering are much more than methods for addressing environmental problems. They offer a framework for achieving innovation. Time and again, companies looking to the future through the lens of green chemistry have enjoyed tremendous environmental and economic returns. What Can GCI Do For Your Enterprise?

Appendix 5.5: Continued

Network	Research
4	Ceres' work falls into four areas: **Company Programs** The Ceres coalition of investment funds, environmental organizations and other public interest groups engages directly with companies on environmental and social issues. Over 70 companies have become "Ceres Companies" by making public commitments to stakeholder engagement, public disclosure and performance improvements through Ceres. Companies believe these actions lead to long-term business value and improved management quality. **Industry Programs** Ceres brings investors and environmental experts together with companies and industries to find solutions to a range of environmental problems. Ceres is coordinating dialogues on climate change in the electric power sector, working with oil companies to protect biodiversity and address climate change, supporting regional efforts to address climate change in the northeastern U.S. and Canada, and working with the insurance sector to adequately assess environmental risks. **Sustainability Reporting** Programs Ceres is widely recognized as a leader in stakeholder engagement and corporate sustainability reporting. Since founding the Global Reporting Initiative in 1997, Ceres has promoted the adoption of the GRI by U.S. companies and has assisted many corporations in developing their reports. Ceres has also developed the Facility Reporting Project and created the Ceres-ACCA Sustainability Reporting Awards to recognize outstanding sustainability reporting by North American companies. **Investor Programs** Ceres works with investors worldwide to improve corporate and public policies on climate change and other environmental, social, and corporate governance issues. As part of this mission, Ceres launched and coordinates the Investor Network on Climate Risk (INCR), an alliance of four-dozen leading U.S. and European institutional investors with assets of over $2.7 trillion. Through INCR, Ceres has mobilized major institutional investors to press companies for climate risk analysis and disclosure. *Industria*l: Ceres brings investors and environmental experts together to work with companies and industries on solutions to a range of environmental problems. Ceres is coordinating dialogues on climate change in the electric power sector, working with oil companies to protect biodiversity and address climate change, supporting regional efforts to address climate change in the Northeast U.S. and Canada, and working with the insurance sector to adequately assess environmental risks.

Appendix 5.5: Continued

Network	**Research**
5	Awards: Green & Sustainable Chemistry Network was established in March, 2000 to promote research and development for the Environment and Human Health and Safety through the innovation of Chemistry. One of our activities, GSCN started "GSC Awards" in 2001. GSC Awards are to be granted to individuals, group or company who greatly contributed to promote GSC through their research, development and their industrialization in the fields such as developing of industrial technology, decreasing environmental bourdon, such as carbon dioxide, waste, landfill, harmful by-products etc., establishing new philosophy/methodology in research fields. The achievements are awarded either by the Minister of Economy, Trade and Industry, or by the Minister of the Environment, or by the Minister of Education, Sports, Culture, Science and technology, depending on their achievements since 2002. In addition, the GSC network newly established GSC Student Travel Grant Awards to promote student's approach on GSC in 2004. The selected students are sent to the student workshop of the international conference on GSC as Japanese representatives.
6	Through our network-its events, programs and technology-individual change-makers are able to deepen relationships and to work together with greater social impact. SVN enables and catalyzes action at three inter-related and coexisting levels: individual, organizational and societal. ▪ *Individual* - SVN cultivates spiritual and leadership development by encouraging the expression of personal values through work and moving beyond leadership as traditional heroism or domination. ▪ *Organizational* - SVN fosters business partnerships and investments that forge new models for social-purpose enterprise, particularly those that generate profitable opportunities in disenfranchised communities. ▪ *Societal* - SVN encourages public service and social action by leveraging the voices of business leaders and the marketing reach of enterprises to bring about social change.

Appendix 5.5: Continued

Network	Research
7	Post-graduate Education and National Research Center For Environmental and Hazardous Waste Management: The Royal Thai Government has established the Higher Education Development Project (HEDP), which is executed by Ministry of University Affairs (MUA), with financial support through a loan from Asian Development Bank (ADB). The HEDP Project aims to develop and strengthen the standard of higher educational system in order to produce quality scientists and engineers to meet the country demand and competitiveness in the international market. Seven Subprojects in different fields were selected on basis of innovative research and the potential for excellence. Cooperation with industry and private sector is emphasized as an effective means to achieve solution and to develop technology applicable to the problems. The NRC-EHWM consists of two complementary activities: Research and Development (R&D) and Post-graduate Programs. The R&D is carried out under the center of excellence that pools resources from universities, government and industry to integrate ideas, expertise and technology transfer. Ultimate outcomes are research findings and new technologies that are applicable and suitable for Thailand. The focused areas of research interest cover treatment technology, remediation technology, ecological and health effect assessment, pollution prevention, policy development and public education/participation. The Center also provides research projects and facility for personnel from private sector and industry or students from the post-graduate programs. Human resource development is a key objective of the NRC-EHWM. A new international post-graduate program in Environmental and Hazardous Waste Management aims to produce quality human resources with the knowledge and skills to manage the environment effectively. Collaboration and partnership with oversea universities in USA and Australia provides excellent opportunity for the students to learn about state-of-the-art technologies, the policy and management system already in place as well as the future global trend.

Appendix 5.6: Original Table

Network	Research
1: Greening of Industry Network (GIN)	
2: Green Chemistry Network (GCN)	
3: Green Chemistry Institute (GCI)	
4: Coalition of Environmentally Responsible Economies (Ceres)	
5: Green and Sustainable Chemistry Network (GSCN)	
6: Social Venture Network (SVN)	
7: National Research Center for Environmental and Hazardous Waste Management (NRC-EHWM)	

APPENDIX 6: NETWORK FOUNDER INTERVIEW ANALYSIS

Appendix 6.1: Founder and network they founded

Name	**Network**
1. Dr. Paul Anastas	Green Chemistry Institute (GCI)
2. Dr. Kurt Fischer	Greening of Industry Network (GIN)
3. Dr. Somporn Kamolsiripichaiporn	GIN; NRC-EHWM: National Research Center for Environmental Hazardous and Waste Management

Appendix 6.2: Goal and future vision

Network	**Response**
1	• Goal: To advance sustainability through the application of green chemistry and green chemistry principles • Future vision: To work as a catalyst with all elements of industry, society, and government to move towards sustainability through the science and technology of green chemistry.
2	• Goal: Many goals • University: goal is to make better connections between university, research and teaching and government policies. There job is to connect to world. Sometimes current research is seen as irrelevant to university teachings – goal is to remedy this. • Environment development: need to look at industrial development in order to help environmental issues. Industrial developments are biggest influences on environmental change these days. • World: message to change world is to change selves first • Future: Have definitely achieved network goals within past years. So now are trying to maintain that, and to create parallel programs with conducting research and university programs. Now vision is to keep action going to keep network going
3	• GIN: They felt that people with common interests are unable to communicate

Appendix 6.3: The start of the network and how it was established

Network	Response
1	• Cofounded with a member of 6 people from industry, academia, national labs in 97 when he was with EPA heading up industrial chemistry branch. he brought the people together. term was coined in 91 by him. • US green chemistry program launched in 91 by EPA • GCI launched in 97 and it was a small virtual institute that worked with building collaboration around the US and around the world • Person asked to be executive director of institute, Breen, he and his group worked to build institute in the US, and to build international chapters. • This is a network of 25 nations, have a number of programs with grants, educational workshops around world, each region people are launching green chemistry networks

Appendix 6.3: Continued

Network	**Response**
2	• Initial conference was like a big planning session. Had an open meeting – about 70 people in 1991, it was an open platform asking how it they would like to see it move forward. Then added to it. Based mostly on people's interest, not so much who they were, and their willingness to work on the issues. • Thinks now planning board is a little big, but is not so much a board of directors as it is a resource board. At any given time about 10 of the people are very active. Don't ask people to resign if inactive. Since operate with small budgets, need people willing to work by email or phone because all over world. Don't have funding to fly people around world to meet. • In the past 15 years, people who were initially managers are now vice presidents. People who were grad students are now professors – so this is how changed. Originally got a hold of people when young, and now they have more influence. • So instead of getting important people, got people who were interested. • 1st steps: • Finding a small core of people with mutual interests who were willing to work on it because a part of their life goals/jobs. At core a volunteer group. Began with his speaking with a Dutch researcher, then put together a planning board of about 12 people in order to say not just their ideas but an expanded group, and then to open it up wider to a broader network. • If were to do it today would probably use more IT work. They started before this. It would be different today. • Conferences are a pretty open forum. Always a strong student component, usually doctoral candidates. They try to make sure that their meetings start something, and not just a meeting since there are so many meetings and people don't want to go but have to. Want it to be different. *Need to keep in mind that people are rewarded for solo work a lot in academia. There is a lot of talk about partnerships and cross-subjects, but they are rewarded for solo work. So it is a minority of academics that work well in partnerships. So different groups may not come together. So we have to make case of why it is in their mutual interest for them to get together on it.

Appendix 6.3: Continued

Network	Response

3	▪ GIN: Started in Europe when Kurt Fischer and Johan Schort met around 13 years ago
	▪ They felt that people with common interests are unable to communicate
	▪ GIN Started out a "loose" network, eventually organized a first conference
	▪ Clark is Director or North Atlantic division at Clark University, Twente University in Netherlands is station for European other division
	▪ Held annual conferences and other small programs during the year. Meetings sparked new ideas and outcome generated from these activities
	▪ Asian division set with cooperation from Chulalongkorn in 1998. US-AEP provided funding
	▪ USAID supported developing countries.
	▪ USAEP-partnership between US and Asia. They developed "policy group"
	    • Intended to bring more attention to environmental-awareness
	    • Started out focusing more on industry, now they focus more on urban planning
	▪ Each year, the conference has a different theme
	▪ US-AEP provided most of the funding to get GIN started

Appendix 6.4: Who is involved in the network and how it has expanded

Network	Response
1	• Government, university, environmental groups, researchers, industries
2	• More proportion of what is needed, between participants. Want to increase NGO participation and government participation. That is the hardest part, they organize themselves because they didn't like how current organizations were being run. Would like to get more of them involved. • NGO – examples: Global Village Beijing (gvbchina.org) – big one in Asia • Who is currently in your network? Who represent • Half University (faculty and grad),20 %business, 20% government, then rest individuals • Planning board list on web – about 40 names, that is a good breakdown
3	• GIN combines government, industry, academy + society

Appendix 6.5: Workshop information

<table>
<tr><th>Network</th><th>Response</th></tr>
<tr><td>1</td><td>
Half-day, couple of hours for high school students
Demonstrations at schools
Week, 2 week summer schools
Should get a good speaker for a lecture
Funding: ACS gives funding, funding from industry, from EPA, national science foundation and philanthropic foundations
</td></tr>
<tr><td>2</td><td>
Workshop a discussion of general issues on a particular theme and then present a problem to try to fix it.
Regional development in a global society: workshops for general public
Funding: Membership plan – half of income pays for journal (not an essential item to have, he had to be convinced to have membership dues); largest source of funding has been government programs, often smaller grant programs; agencies will often have a certain amount of money can give where want; US EPA; all funding within certain limits; European union
Link on webpage, bottom of home page link for sponsors – a lot of companies, not sought out business sponsorships for normal stuff, but for different local conferences or fellowships
Mainly volunteer labor
But now as they are moving on from where they are now with more action projects, will need normal funding.
</td></tr>
<tr><td>3</td><td>
GIN: First conference held in Asia took place in 2001

Participants use conference as a “stage” to grow support for their cause
Went on tour to several Asian countries to understand their issues and carried out specific workshops in that country, specific to their needs
Hong Kong, Malaysia, Philippines
Brought local officials of government
Go to federation of industry, chamber of commerce etc.

GIN combines government, industry, academy + society
Future workshops: GIN is trying to put on more specific workshops that apply to specific needs in particular regions

US workshop next week about free trade and fair trade
Sustainable consumption

</td></tr>
</table>

Appendix 6.6: General Table Used

Interviewee	Response
1	
2	
3	

APPENDIX 7: DR. PAUL ANASTAS' STEPS TO CREATING A GC NETWORK

FOUR STEPS:
Identify all of people – not just at her university, but other universities that are doing green chemistry but might not know they are doing it – compile an inventory of what is going on then invite all of people to become a part of a national green chemistry council/board – could have a dozen groups of people pulling together – says needs to pull together to work to raise public awareness
Establish an industrial advisory board – companies who are or should be interested in doing green chemistry and group of academics explains why green chemistry is relevant to them
Establish a national award to recognize accomplishments in green chemistry for industries – industries will be happy about this – motivate them to talk about all of the great work they are doing - when ask what motivates people in Thailand – launch a prize sponsored by the princess if professors motivated by getting awards and recognitions, giving her something to be beneficial to Thailand, to science – she will recognize that green chemistry is looking to make a dramatic impact on sustainability and is recognized by top institutions in world she will fund it
This has been done in US, Japan, UK.
Use a combination of the work being done in research labs and work done in industry to **communicate** back to research funding agencies like the government to reinforce the funding of green chemistry research
Then use products of funding to build into education of younger people.

Uses the same models in every country, sometimes they are done in different orders.

APPENDIX 8: GREEN CHEMISTRY EXPERTS' INTERVIEW ANALYSIS

Appendix 8.1: Interviewee and location and Type of Interview

Name	Interview Type	Location
1. Dr. John Warner	Telephone	UMass Lowell, MA
2. Dr. Julie Haack	Telephone and Face-to-Face	University of Oregon, OR
3. Dr. Denyse Wicht	Email and Telephone	Suffolk University, Boston, MA
4. Dr. Richard Gurney	Email and Telephone	Simmons College, Boston, MA
5. Dr. Mike Zarworotho	Email and Telephone	Florida State University, FL
6. Dr. Ed Brush	Email and Telephone	Bridgewater State College, MA

Appendix 8.2: Green chemistry workshops information

Responses to: Question 1, Appendix 1

Name	Response
1	• Most important thing for running a workshop is authenticity of people running it. Make sure the people know what they are saying and are actually doing green chemistry • Format, available audience, and how to put the workshop on will depend on culture. J. Warner has put on workshops in 30 countries. ▪ He always tries to target younger faculty and graduate students to attend. They are younger and more open to new ideas like green chemistry • Culture is very important. Sometimes permission is required from graduate advisors for students to attend workshops, this can often prevent them from coming. • Flyers are sent to every chemistry department in NE including WPI, workshop is free. No WPI student has ever attended. • Good to have influential faculty member running workshop. Possibly 20 minute presentations at workshop. Make sure to include applications/opportunities in green chemistry

Appendix 8.2: Continued

Name	Response

2	• There are around 20 people who come each time
	• Set up so that they can choose which reactions that are most applicable to their needs
	• Depends on the interest level of students
	    • Higher interest=higher attention span
	• Good to "break it up". Some lecture, then some group work or interactive component, then hanging out, let them interact and discuss possible applications
	• After 20 minutes of lecture, you loose people's attention
	• Consider having a speaker on research done in green chemistry, interesting
	• Essential to provide vocab, definitions, contacts, history of GREEN CHEMISTRY
	    • Get everyone "on the same page"
	• Then, show examples. That is, explain examples…not physical demonstrations
	    • 2 or 3 examples sufficient
	• Provide real world cases
	• Keep in mind-
	    • What is the big picture? Impact on environment…why does this matter?
	• Explain policy
	    • Show students different facets
	• Believes that a ½ day workshop will most likely be the best amount of time
	• Believes it will be very difficult to get undergraduate students to give up a weekend or a lot of free time

3	• I don't think it falls under the definition of "workshop" but I taught a short course to undergraduate students on Green Chemistry at Wellesley College in January of 2005. I gave a talk on this course at the Green Chemistry and Engineering conference in D.C last June and I have attached the PowerPoint presentation here for you to review. • The course was for students, but the conference talk was for mostly other educators, but there were also some students present.

Appendix 8.2: Continued

Name	Response
4	• I have participated within a The Green Chemistry in Education workshop through the University of Oregon, organized by Jim Hutchison. I was able to present models for teaching Green Chemistry in the college level. Jim's workshop is an exceptional model for involving other educators in the Green Chemistry realm. I am certain that we could work with Jim on transferring his model to a school in Thailand. • I will also be participating in and running a workshop at the New England Association of Chemistry Teachers this summer. I will be demonstrating a lab originally developed in the Hutchison labs that is suitable to introduce Green Chemistry into middle, junior high, and high school students. It is also a great demonstration lab that can be done in an after school outreach program. I have personally introduced roughly 65 middle school students to the laboratory with great success through a summer camp program I helped organize and facilitate at Simmons.
5	• I have organized several meeting, not particularly in green chemistry. They were for many people from industry. It was a day long workshop. It was mainly lecturer some hands-on with computer databases. It was funded by industry organized by a company that puts on workshops and industry pays a fee to attend. I hired a company called IQPC to run the workshop. I was responsible for the academic content and they did all the publicity and handouts. • Not really. If it's an area not familiar with, I don't think they'd be different. You have to assume your audience knows nothing about a particular subject. I use the same material in teaching.
6	• *non-response*

Appendix 8.3: Starting place for green chemistry at a University

Responses to: Question 2, Appendix 1

Name	Response
1	• In reality, this workshop is really for faculty. Students will like it no matter what. Find a way to get faculty involved or to attend. • UO workshop is different because it is self selected. These people get a "charge" out of being in the lab. Our audience might be different. Graduate students or even undergraduates already spend a lot of time in the lab, and are tired of it. • Suggest having students look at presidential green chemistry award challenge write ups and go 12 principles and determine how they apply to each award. Get students thinking about how to assess this. • "Elevate" green chemistry to a science itself. Analyze green chemistry. Some lab component is also good, but analysis of what reaction is doing is better.
2	• Depends on what your goals are. What do you want the seminar to do? Do you want to stimulate interest in green chemistry by educating the students so that they will put pressure on faculty to teach it? Is this a reasonable expectation in Thailand? It would not work well in the US. What is the process for determining course content in Thailand? Do they have a national curriculum? What are the current barriers to incorporating green chemistry into the curriculum?
3	• *non-response*
4	• *non-response*
5	• I have no feel for the context of Thailand. I don't know the background of the students in Thailand. Or what knowledge they already know. I think in the United States would be a good start for students, but more for professors. My research group is focused that way. In organic chemistry it needs to be a concentration. We started by professors and graduates going to workshops and then teaching what they learned in classes. I don't know if a class is needed, I think it should be integrated into the current curriculum more.
6	• The difference is in the chemistry background of each group. For students you really need to first "teach" some background, "test" this knowledge through a worksheet, then "apply" the knowledge through a hands on demonstration. For professors who already have a strong chemistry background, the problem is convincing them that green chemistry is important and relevant to their teaching and research. The thing that got green chemistry going at BSC was a seminar by Dr. John warner (UMASS Lowell) on green chemistry. But that alone is not enough. You need faculty who really but into the idea to keep it going. This is best done through incorporating green chemistry into the chemistry curriculum, and through research participation by faculty-students.

Appendix 8.4: Opinions of benefits of a workshop to initiate green chemistry vs. curriculum

Responses to: Question 3, Appendix 1

Name	Response
1	• Introducing green chemistry without proper background could be too much at once. • People are quick to reject things they do not know about.
2	• Seminars are a nice way to educate a group of people about a topic. How you present the topic depends on the outcomes you expect. It's kind of like writing a persuasive essay. What is the thesis of your presentation and what kinds of information will you use to support your thesis? The audience analysis helps you to choose content that will be the most effective.
3	• *non-response*
4	• *non-response*
5	• Basically introductory organic chemistry needs to introduce green chemistry in the lab. We tend to be focused on theory versus practice.
6	• You need a plan or strategy. I think that a seminar or a seminar series is a great idea, but what will be the follow up? As I wrote above, you still need faculty involvement to keep the momentum going.

Appendix 8.5: Changing curriculum

Responses to: Question 4, Appendix 1

Name	Response
1	• He designed PhD program at UMASS Lowell. • Faculty at UMB would not change curriculum. Requirements for ACS accreditation in chemistry made it impossible to fit new materials into the curriculum. • Warner's solution was to create entirely new degree. Currently, 250 people apply to the PhD program in green chemistry. • Changing the minds of faculty who do not believe in green chemistry will not happen.
2	• How green chemistry got to UO • Professors wanted to "modernize" chem. dept. • Hutchison and Doxee found green chem. • Went to workshops by Warner, learned how to do it • National science foundation helped develop curriculum, grad students helped develop labs. • 5 years in the making, grew in size and popularity every year.
3	• *non-response*
4	• *non-response*
5	• Yes, mine is evolving all the time. I have converted most of my material to PowerPoint. It is constantly evolving and changing. No one checks what I change except the American Chemical Society checks all my material like tests etc. every five years.
6	• The biggest challenge with any new idea (no matter how great it is) is that something or someone has to change. You can not "force" any faculty to change the way they teach, or the direction of their research. You can lead by example, and if the students are interested in green chemistry, that will usually help "tip the scales." Your school may want to adopt an award for "green" or "sustainable" ideas to faculty and students to help get the ball rolling.

Appendix 8.6: Movement of change

Responses to: Questions 5 and 6, Appendix

Name	Response
1	• Replace labs, lecture materials etc. do not add onto them. • Generally, faculty members do not enjoy teaching labs. Not prestigious, looked down on. However, Warner feels that this is the most important part of the chemistry education. ▪ For this reason, most people do not really care about efforts to replace labs. • Best way to implement change: incremental change initiated by a tenured Professor who is willing to stand up for what they believe in (green chemistry) *Funding:* • "everyone" is seeking funding for green chemistry projects. Need to have big names endorsing the proposal. • Talk to GCI/Paul Anastas about funding our project
2	• This is a huge question and varies according to specific situations. As we have worked with faculty around the US, we have learned that each faculty member faces different challenges that are specific to their institution. These challenges are often related to the size of the institution, how curriculum is developed, funding, how faculty are judged for promotion and tenure, etc. What are the unique challenges in Thailand? Once we know the challenges, then it's much easier to talk about possible solutions.
3	• I believe the students that took the Green Chemistry Course were convinced of the benefits. • I was convinced of the benefits of Green Chemistry when I was working in industry. I felt so strongly about incorporating Green Chemistry into student training that I changed the focus of my career and went into education.

Appendix 8.6: Continued

Name	Response
4	• I have taught a course on Green Chemistry for the past four years at the college level, and it has been developed to target both majors and non-majors in science. It has had several iterations and I have spent the majority of the past 5 years considering different ways of bringing the material to the classroom. I am currently developing a learning community style course that will bridge two separate courses, Green Chemistry and Environmental Ethics, to be offered at Simmons College Spring 2007. Students will be enrolled in both courses as well as an integrative seminar where they will participate in 5 major case studies, which will consider the chemistry and ethics of serious environmental tragedies, such as Bhopal. After learning of the tragedy and the reason such chemicals were produced we will focus on the greener technologies or chemistry's that have emerged recently which are much more benign and greener by design. At the end of the semester students will choose one of the five projects and be encouraged to become activists and direct local change, on the topic. • Also, I have adopted and developed several laboratory experiments that have been extremely successful in the teaching realm for introducing the concepts of green chemistry for freshman and sophomore level college courses. I have a model that I am working to publish soon, that engages the students to a great degree in greening their own experiment in an organic chemistry course.
5	• There was not a need. No approvals needed. We have some requirements of accreditation. Every five years we have to submit all the material in our curriculum. The American chemical Society looks over everything but there is a lot of leeway and freedom to add extra material after the basics are covered. We added a course in drugs and pharmaceuticals; it seems to be very popular among students although it is not a required course.
6	• I teach organic chemistry, and I believe in the green chemistry philosophy. Its really easy, you just do it! There were no "steps", but I did start with research students who were given a project to take an organic lab, and "re-engineer" it to make it greener. I then began incorporating green chemistry topics into my lectures, and expanded my research. I go to green chemistry conference, and take students along so that we can see what others are doing. • The biggest challenge with any new idea (no matter how great it is) is that something or someone has to change. You can not "force" any faculty to change the way they teach, or the direction of their research. You can lead by example, and if the students are interested in green chemistry, that will usually help "tip the scales." Your school may want to adopt an award for "green" or "sustainable" ideas to faculty and students to help get the ball rolling.

Appendix 8.7: Future of green chemistry

Name	**Response**
1	• The United States is leading the way in green chemistry. • Small scale chemistry is not green chemistry! • Chemistry VS. Environmental science, green chemistry is right between the two. • Using the name green chemistry has become a marketing strategy to get funding for projects that may not be entirely green chemistry.
2	• *non-response*
3	• I think Green Chemistry needs to be introduced when students are first introduced to chemistry--high school, if not sooner. Students need to be reminded of the benefits of Green Chemistry constantly as they move through college courses. Ideally, learning chemistry = learning Green Chemistry.
4	• *non-response*
5	• Look into Singapore and make world research and university teaching I visited there and they have a great education program and research facilities.
6	• *non-response*

Appendix 8.8: General Table Used

Name	**Response**
1. John Warner	
2. Julie Haack	
3. Denyse Wicht	
4. Richard Gurney	
5. Mike Zarworotho	
6. Ed Brush	

APPENDIX 9: FACE-TO-FACE INTERVIEW WITH DR. JULIE HAACK 2/24/06

After presenting our final presentation to Dr. Julie Haack

On the project's final goal: Teaching students to think like a green chemist is the goal of Green chemistry is about constantly holding workshops and lectures to different groups of people. If I give a lecture/workshop to 100 people, maybe only 2 people will think it is interesting. But those two people will go and tell their friends and come back with new people the next lecture. Say for me, I will go back to my university then call some other people at different universities and get all my educational friends to go. It also bringing in people that didn't know they were doing green chemistry. I think teaching green chemistry is really "catalytic" in a way. It's like peeling an onion. Once there is a core group of people interested, the audience starts to grow rapidly and acts as a snowball effect.

On communicating with industry: There is a problem with trying to outreach to industry. What happens when businesses don't want to share their intellectual properties? They have competition and are reluctant to share their secrets. With these issues it really helps if green chemistry experts, such as Paul Anastas, go and consult with the company one on one and sign a disclosure agreement. It provides a less public and secretive environment. Don't expect industries to share the green chemistry they have been doing because they don't want to give away their secrets. Industry has lead the way in green chemistry because they have kept these green chemistry ideas a secret, but academia is certainly making a lot of headway to catch up. Some representatives (such as the board of directors or core group of people) might go to the industries and present ideas to the industry such as solvent lists and the principles of framework.

Green chemistry is like getting someone to eat their vegetables: Many schools debate if they should focus on green chemistry in curriculum, have a Ph. D program, or create a new green chemistry course. I suggest whatever they think is best. It's like eating vegetables, even with sugar on it or frying them they are still vegetables.

Chulalongkorn's Unversity Chemistry Space: When I visited Chulalongkorn University today on the tour they said the capacity of the labs were 60 students and the capacity of the lecture hall was 200 students.

On a small group in a workshop in Thailand: The first time around 20 students would be optimal so that it is less intimidating for students and they can feel comfortable to ask questions. The smaller the group, the less intimidating it is. I find that in classes that have smaller numbers of students I get a lot more group interaction.

On further recommendations for Thailand: There should be many more workshops to come after the first one to broaden the exposure and bring in more people.

On the punch line: Early knowledge of chemistry focused on command and control techniques. Chemists didn't have enough knowledge to know that they were producing toxic chemicals or that there were alternatives. Before they couldn't chose. Now they have the knowledge to. If they chose wrong, it is a bad decision for them. When they didn't have the knowledge, there were many issues with it. There isn't a 100% guarantee that an accident or spill will not occur. The risk here is hazards and exposures. The alternative approach of green chemistry has many advantages such as human health, economics, workers safety, competitiveness, and looking better in the public eye.

What lab to offer in a workshop: I like the high visual not too technical labs. It's one thing to hear about it, it's another to do it. Hands on laboratories work best. With 20 students, they can go to the lecture together than go to the laboratory together and communicate with each other. They will share ideas better this way. Hands on laboratories are a reinforcement of knowledge. The laboratories are relaxed and a very powerful learning technique. In fact, I use this to teach faculty and test experiments. Faculty are very distrusting, more so than students. We offer 3 or 4 day labs sessions and have the faculty pick their reactions so they can see the advantages of green chemistry for themselves.

Why offer a workshop? The students that attend this workshop will go back to the classroom and push for green chemistry. Students respond very well to green chemistry and it also makes the professors more interested in teaching green chemistry. By offering a workshop this will plant a seed in the student's mind for them to think about. Then when they reach industry, even if the industry isn't doing green chemistry, the students will be thinking like green chemists.

What is the future? The future of green chemistry is probably in nanochemistry. Also it could be green material sciences.

APPENDIX 10: INTERVIEW WITH DR. CHRYSANTHE DEMETRY ABOUT WORKSHOPS 1/12/06

Camp Reach received initial funding from the National Science Foundation
There was an IQP that designed camp reach and researched ideas about summer camps
The goals and objectives of Camp Reach are:
-generate and sustain interest
-improve understanding
-enhance self confidence
-improve girls reactions to engineering and technology

-The application process is based on a first come first serve basis and the young women have to write an essay a time in their life when they had to "work hard on something"
-There were 30 girls accepted because the lower number of 30 is more manageable and had a greater impact than accepting a number such as 200 and giving them just a brief introduction to engineering and technology
-The program costs $45,000 a year because it's a residential program
- It is funded by corporations and foundations
-There is a director of corporate relationships
-The budget can be found at camp reach's website www.wpi.edu/+reach under dissemination
-G.E.M.S. is from the women's program office – it offers activities in chemistry
-lengths of lectures are kept short (around 5 minutes) because of the attention span of the age group. We usually try to make it interactive by providing leading questions so that we engage the young women
- We got the curriculum from Wisconsin, a chemical education curriculum
- you should try to make topics with green chemistry in the student's everyday lives like in Camp reach we make chewing gum and chapstick – we have found the young women show a lot of interest in these reactions
-I suggest you provide the teachers with a book on reactions that they can go back to their schools with
-the IQP that designed Camp reach focused on the following topics: education psychology, logistical constraints, validity of proposal and "hands on experience", the learning outcomes vs. attitude outcomes

APPENDIX 11: PAST CHEMISTRY WORKSHOP SCHEDULES AT CHULALONGKORN UNIVERSITY

Appendix 11.1: Principles and Practice in Capillary Electrophoresis

Schedule -Principles and Practice in Capillary Electrophoresis - 1 day Workshop	
8.00 - 8.45	Registration
8.45 - 9.00	Opening Cermony
9.00 - 10.20	Principles and optimisation in capillary electrophoresis (Lecture)
10.20 - 10.30	Coffee Break
10.30 - 11.00	Micellar electrokinetic chromatography (MEKC) (Lecture)
	and Microemulsion electrokinetic chromatography (MEEKC)
11.00 - 12.00	Instrumentation and Applications (Lecture)
12.00 - 13.00	Lunch
13.00 - 13.50	CEC & Microchip CE (Lecture)
13.50 - 14.00	Coffee Break
14.00 - 16.00	CE Simulation, Introduction of CE instrumentand CE analysis of anions (Laboratories)
	Micellar electrokinetic chromatography, Microchip capillary electrophoresis

Appendix 11.2: Chitin and Chitosan Workshop

Schedule - Chitin and Chitosan Workshop - 3 days	
Day 1	
8.30 - 9.00	Registration & Opening Cermony
9.00 - 10.15	Introduction Program of Workshop- History and Importance
10.15 - 10.45	Coffee Break
10.45 - 12.00	Biology and Chemical Process - (Lecture)
12.00 - 13.00	Lunch
13.00 - 15.15	How to Produce Chitin and Chitosan Chemical(Laboratory)
15.15 - 15.30	Coffee Break
15.30 - 16.30	How to Produce Chitin and Chitosan Biology(Laboratory)
Day 2	
8.30 - 9.00	Conclusion and Presentations of Laboratory 1 (Lecture)
9.00 - 10.15	Further Experiments from Laboratory 1 (Laboratory)
10.15 - 10.30	Break
10.30 - 12.00	Further Experiments from Laboratory 2(Laboratory)
12.00 - 13.00	Lunch
13.00 - 14.30	Analysis and test properties of Chitosan (Lecture)
14.30 - 14.45	Break
14.45 - 16.30	Experiments and tests of Chitosan (Laboratory)
Day 3	
8.30 - 9.00	Conclusion and Presentation of Laboratories 1,2 and 3 (Lecture)
9.00 - 10.15	Application of Chitin and Chitosan in agriculture (Lecture)
10.15 - 10.30	Coffee Break
10.30 - 12.00	Further experiments from Laboratories 1 and 2 (Laboratory)
12.00 - 13.00	Lunch
13.00 - 15.15	Further experiments from Laboratory 3 (Laboratory)
15.15 - 15.30	Break
15.30 - 16.30	Further experiments from Laboratory 3 & Conclusions (lab and lecture)

Appendix 11.3: Young Science Talent's Fun Time at National Science Museum

Young Science Talent's Fun Time at National Science Museum - 1 day Schedule	
Day 1	
9.30 - 10.00	Register
10:00	Separate into Groups
10.00 - 10.10	Welcoming Speech
10.30 - 12.00	Ice Breaking with Team Work Activity (Hands on)
12.00 - 13.00	Lunch
13.00 - 13.30	Explanation of Walk Rally rules (Lecture)
13.30 - 15.30	Walk Rally in Science Museum (Hands on)
15.30 - 16.00	Break
16.00 - 17.00	Science Show (Hands on)
17:00	Announcement of Prizes
17.00 - 18.30	Check into Dormitory
18.30 - 20.00	Dinner
20.00 - 22.00	Interactive Science Drama and games (Lecture)
Day 2	
8.00 - 9.00	Breakfast
9.00 - 12.00	Creations from the box (Hands on)
12.00 - 13.00	Lunch
13.00 - 14.00	Presentations (Hands on)
14.00 - 16.00	Discussion about Science (Lecture)
16.00 - 17.00	Closing Ceremony

APPENDIX 12: SAMPLE SCHEDULE

Schedule – Green Chemistry workshop for Undergraduate students - 1 day Workshop	
8.00 - 8.30	Registration
8.30 - 9.00	Opening Ceremony
9.00 - 10.20	Lecture
10.20 - 10.30	Coffee Break
10.30 - 12.00	Laboratory
12.00 - 13.00	Lunch
13.00 - 13.50	Laboratory
13.50 - 14.00	Coffee Break
14.00 - 15.00	Debriefing and Analysis

APPENDIX 13: EXAMPLES OF PAST BUDGETS FROM WORKSHOPS IN APPENDIX 11

Appendix 13.1: Principles and Practice in Capillary Electrophoresis

Thailand Workshop Logistics
Workshop: Principles and Practice in Capillary Electrophoresis
Type of Workshop: Lecture and Laboratory
Time: 1 day
Accommodations: none - one day only
Attendance: 60 people
Chulalongkorn Professors/Researchers - 20 people
Researchers from industry - 30 people
Students - 10 people

Budget

Income:		Baht
Registration		FREE
Income from company sponsorship		57,500
	Total	**57,500**
Expenses:		
People		
Payment for 1 day lecturer 3,000 baht/hr @ 3 ppl		9,000
Payment for laboratory assistants Micro Chip CE 1,000 baht/hr - 4 assistants for 2 hrs		8,000
Payment for laboratory assistants 300 Baht/hr - 4 assistants for 2 hours		2,400
Payment for laboratory assistants 300 Baht/hr - 2 assistants for 4 hours		2,400
Payment for Laboratory assistants 150 Baht/hr for 2 assistants for 4 hours		1,200
Payment for Laboratory worker @ 1 person		500
Location		
Payment for Lecture Hall @ 5,000 baht/day		5,000
Food		
Payment for lunch 50 baht/meal/person for 70 ppl		3,500
Payment for coffee break 25 baht/70person/2 meal a day		3,500
Materials		
Materials and Chemicals		20,000
Publicity		
Pamphlets		2,000
	Total	57,500
	Income Total	57,500
	Expenses Total	57,500

Appendix 13.2: Chitin and Chitosan Workshop

Thailand Workshop Logistics
Workshop: Chitin and Chitosan
Type of Workshop: Lecture and Laboratory
Time: 3 days
Accommodations: go home everyday
Attendance: 25 people

Budget

Income:		Baht
Registration – 1,000 baht/person x 25 people		25,000
Income from outsource		50,000
	Total	**75,000**
Expenses:		
People		
Payment for assistant lecturer 400 Baht/day - 3 assistants needed x 3 days		3,600
Payment for 1 day lecturer 1,000 baht/day @14 people		14,000
Location		
Payment for Location @ 5,000 baht/day		15,000
Food		
Payment for lunch 130 baht/meal/person for 35 ppl x 3 days		13,650
Payment for coffee break 50 baht/35 person/6 coffee for 3 days		10,500
Materials		
Pamphlet		5,000
Materials		5,000
Payment to Institutes		7,500
Miscellanous		750
	Total	75,000
	Income Total	75,000
	Expenses Total	75,000
	Total	0

<u>APPENDIX 14: SAMPLE BUDGET</u>

Thailand Workshop Logistics
Workshop: Proposed Undergraduate Student Green Chemistry Workshop
Type of Workshop: Lecture and Laboratory
Time: one day
Accommodations: none - one day only
Attendance: 30 Students

$6,000 US dollars =approximately 240,000 baht

Budget		
Income:		Baht
Registration		FREE
Income from outsource		240,000
	Total	**240,000**
Expenses:		
People		
Payment for 1 day lecturer 3,000 baht/hr @ 3 people		40,000
Payment for laboratory assistants 300 Baht/hr - 3 assistants for 8 hours		7,200
International Fares for invited speakers from outside the region		130,000
Location		
Payment for Laboratory 1000 baht/hour - 1 labs for 7 hours		7,000
Payment for Lecture Hall @ 5,000 baht/day		5,000
Food		
Payment for lunch 80 baht/meal/person for 30 ppl		2,400
Payment for coffee break 70 baht/person/meal - 2 breaks, 30 ppl		4,200
Materials		
Materials and Chemicals		30,000
Publicity		
Pamphlets		2,000
Mailings		2,000
Miscellanous		10,200
	Total	**240,000**
	Income Total	
	Expenses Total	**240,000**

APPENDIX 15: GREEN CHEMISTRY GRANT FROM GCI

Green Chemistry Institute
American Chemical Society
1155 Sixteenth Street, N.W. • Washington, D.C. 20036
Phone: 202-872-6102 • Fax: 202-872-6206
URL: http://chemistry.org/greenchemistryinstitute • E-mail: gci@acs.org

Green Chemistry Institute

Green Chemistry Institute
Developing/Emerging Nations Grants Program
Request for Proposal

Background

Due to the generous and thoughtful funding support of the IUPAC Chemical Research Applied to World Needs Future Actions Committee (CHEMRAWN XIV FAC), the Green Chemistry Institute (GCI) is able to provide several seed grants to assist developing/emerging nations in advancing Green Chemistry. One of the goals of the CHEMRAWN XIV FAC's action plan was to facilitate the research, education, outreach, communication, and industrial implementation of Green Chemistry around the world. This Green Chemistry Institute Developing/Emerging Nation (GCI-DEN) grants program targets activities that build collaborations among GCI chapters in developing/emerging nations with chapters in industrialized nations, regardless of where the project actually takes place. While Green Chemistry is applicable in all nations, there is perhaps the greatest need for the benefits to human health, environmental, and economic development in the targeted nations.

Program Description

Overview

The GCI-DEN Program will provide small seed grants to individuals or groups sponsored by a GCI international chapter(s) to promote Green Chemistry in developing/emerging nations. The purpose of the GCI-DEN Program is two-fold:

1. To assist in building Green Chemistry capacity in developing/emerging nations.
2. To build collaborations and lasting relationships between GCI chapters in developing/emerging nations.

The scope of activities that can be considered for grants is very broad and can include research, education and training, outreach, communication, industrial or practical application of Green Chemistry technologies, and scientist exchange. Fellowships, workshops, symposia, material translation and distribution, and development of communication tools are among some of the anticipated activities.

Potential projects might include:

- Purchase and distribution of educational materials
- Projects to translate existing materials for broader local distribution
- Equipment purchase and installation to facilitate green chemistry research
- Regional green chemistry workshops

• Seed funding for proposal development for larger project funding

• Government/industry meetings to promote Green Chemistry (possibly leveraged with a visit by a GCI person paid by GCI)

While individual activities such as travel grants can be considered, all proposals will be evaluated for their ability to make the largest impact on the largest number of people to advance Green Chemistry. Typical grant size is expected to be in the $2,000-$5,000 range; however, larger grants may be considered for more ambitious projects. The criteria for assessing the proposals for funding will include:

1. Advances Green Chemistry in Developing/Emerging Nations – The proposed activity should explicitly advance the use of Green Chemistry as opposed to traditional approaches to environmental assessment/clean-up or industrial chemistry. The activity should explicitly impact the developing/emerging nation as opposed to expanding industrialized nations' efforts.

2. Builds Collaboration and Lasting Relationships Between GCI Chapters – While activities involving single GCI chapters can be considered, those activities that include multiple GCI chapters will be more competitive. For those proposed activities with active engagement from GCI chapters, the more chapters included, the stronger the proposal.

3. Maximizes the Impact by Leveraging Resources – Proposed activities that involve a single individual are not as competitive as those proposals that involve and impact many people or organizations. Projects that will be able to obtain additional funding or resources due to GCI funding will be more competitive than those where GCI is the sole source of funding.

4. Long-term Impact – Activities that provide a lasting impact for the future will be regarded more highly than those that have a one-time impact.

Eligibility Criteria

Primary consideration of proposals will be given to those submitted or endorsed by one or more GCI international chapter(s). However, any individual or organization may submit a proposal for funding if able to demonstrate the capability and knowledge in Green Chemistry to complete the project.

Application Process

The proposal application **must** include the following elements to be considered:

1. Cover page with the following information:

    a) Project Title

    b) Name of Submitting Institution and Individual

    c) Contact Information (Name, Address, Phone, Fax, E-mail, URL)

    d) Abstract of Proposal (Not to exceed 100 words)

e) Category of Project (Research, Education, Outreach, Implementation, Other - specify)

2. List of all sponsoring GCI Chapters (if applicable) and summaries of major Green Chemistry activities by all sponsoring chapters (not to exceed two (2) pages for each GCI Chapter summary)

3. Proposal Narrative- applicants are advised to address the following topics (not to exceed five (5) pages)

a) Project description

b) How the project advances Green Chemistry

c) How the project impacts the developing/emerging nation

d) How the project builds relationships between GCI Chapters

4. Detailed budget, describing how and over what time frame the funds will be spent (not to exceed one (1) page)

Deliverables
Proposals selected will be required to submit a report detailing the outcome of the project (not to exceed five (5) pages) along with one copy of any materials generated by the project, within one year of the project funding.
Deadline
Applicants are encouraged to apply as early as possible. Proposals postmarked by April 15, 2006 will be reviewed and considered for funding. Decisions will be made on a rolling basis.
Format & Logistics
Electronic submissions should be sent to gcigrants@acs.org with "GCI-DEN Grants" in the subject line.
Hardcopy submissions may be mailed to:
Green Chemistry Institute
American Chemical Society
1155 Sixteenth Street, NW
Washington, DC 20036
Phone: (202) 872-6102
Alternatively, applications may be faxed to (202) 872-6206.

APPENDIX 16: OUTLINE OF PRELIMINARY GRANT PROPOSAL

Application Process
The proposal application must include the following elements to be considered:
1. Cover page with the following information:
a) Project Title – Developing a Strategy for Integrating Green Chemistry in Thailand

b) Name of Submitting Institution and Individual - Chulalongkorn University, Dr. Supawan Tantayanon

c) Contact Information (Name, Address, Phone, Fax, E-mail, URL) –

d) Abstract of Proposal (Not to exceed 100 words) - This grant proposal addresses the need to educate students about green chemistry through a one day workshop for undergraduate students held at Chulalongkorn University. In addition, this workshop provides the first step towards the future of a green chemistry network in Thailand. The workshop would be open to all undergraduate students in Thailand and has a proposed budget of 6,000 U.S. dollars.

e) Category of Project (Research, Education, Outreach, Implementation, Other - specify) - Education

2. List of all sponsoring GCI Chapters (if applicable) and summaries of major Green
Chemistry activities by all sponsoring chapters (not to exceed two (2) pages for each GCI Chapter summary)-

- Thailand Green Chemistry Chapter is the sponsor
- Previous activities: Workshop for educators in 2002

3. Proposal Narrative- applicants are advised to address the following topics (not to exceed five (5) pages)
a) Project description
The purpose of this workshop is to generate interest in undergraduate students about green chemistry by providing hands on activities and laboratories. The workshop will serve as a feeder program to Chulalongkorn University's future green chemistry program. After graduation, the Chulalongkorn graduates can practice green chemistry in industry. The purpose of the workshop extends further than simply educating undergraduates about green chemistry. Since the workshop is the first step in creating a larger green chemistry network, the purpose contains an extension of the workshop by serving as a feeder program to Chulalongkorn University's graduate program. The workshop will contain a small lecture portion and a large laboratory component for an undergraduate student workshop to hold interest in students. The proposed schedule is located in Table 1.1. The estimated attendance for this workshop would be twenty to thirty undergraduate students in addition to the staff and speakers. Publicizing will be in the form of pamphlets, letters, flyers and emails. In addition, Professors will announce during

chemistry lectures that there will be a workshop and give a quick introduction to green chemistry.

Table 1.1 – Proposed Schedule of one day workshop for Undergraduate Students

Schedule – Green Chemistry workshop for Undergraduate students - 1 day Workshop	
8.00 - 8.30	Registration
8.30 - 9.00	Opening Ceremony
9.00 - 10.20	Lecture
10.20 - 10.30	Coffee Break
10.30 - 12.00	Laboratory
12.00 - 13.00	Lunch
13.00 - 13.50	Laboratory
13.50 - 14.00	Coffee Break
14.00 - 15.00	Debriefing and Analysis

This project is the first step in a larger context of developing a green chemistry network in Thailand. The remaining steps can be found in Table 1.2.

b) How the project advances Green Chemistry

- Establishes knowledge of students about green chemistry
- Provides a feeder program for Chulalongkorn University and Thailand
- Establishes initial contact of students who will one day be working in industry

c) How the project impacts the developing/emerging nation

- By developing Green Chemistry it can be eventually implemented into Thailand's chemical industry and help clean up the estimated 950,000 tons of hazardous waste that are produced annually by industries in Thailand (Thailand Country Profile, 2002).

d) How the project builds relationships between GCI Chapters

- Only held by Thailand GCI's chapter, yet still builds a relationship by inviting experts from other GCI Chapters
- Can produce the results of successes and failures to other GCI Chapters to inform them if they should hold workshops for students
- If these experts do come as lecturers, it gives Thailand's chapter a chance to discuss new ideas and ideas that are being explored in different parts of the world

4. Detailed budget, describing how and over what time frame the funds will be spent (not to exceed one (1) page)

Thailand Workshop Logistics
Workshop: Proposed Undergraduate Student Green Chemistry Workshop
Type of Workshop: Lecture and Laboratory
Time: one day
Accommodations: none - one day only
Attendance: 30 Students

$6,000 US dollars =approximately 240,000 baht

Budget

Income:		Baht
Registration		FREE
Income from outsource		240,000
	Total	**240,000**
Expenses:		
People		
Payment for 1 day lecturer 3,000 baht/hr @ 3 people		40,000
Payment for laboratory assistants 300 Baht/hr - 3 assistants for 8 hours		7,200
International Fares for invited speakers from outside the region		130,000
Location		
Payment for Laboratory 1000 baht/hour - 1 labs for 7 hours		7,000
Payment for Lecture Hall @ 5,000 baht/day		5,000
Food		
Payment for lunch 80 baht/meal/person for 30 ppl		2,400
Payment for coffee break 70 baht/person/meal - 2 breaks, 30 ppl		4,200
Materials		
Materials and Chemicals		30,000
Publicity		
Pamphlets		2,000
Mailings		2,000
Miscellanous		10,200
	Total	**240,000**
	Income Total	
	Expenses Total	**240,000**

Deliverables
Proposals selected will be required to submit a report detailing the outcome of the project (not to exceed five (5) pages) along with one copy of any materials generated by the project, within one year of the project funding.

<u>APPENDIX 17: GREEN CHEMISTRY REACTIONS FOR PRIMARY STUDENTS</u>

Appendix 17.1: Airness Awareness!

American Chemical Society. (2003, Nov. 17). *Airness Awareness.* Retrieved February 15, 2006, from http://www.chemistry.org/portal/a/c/s/1/wondernetdisplay.html?DOC=wondernet\activities\atmosphere\airness.html

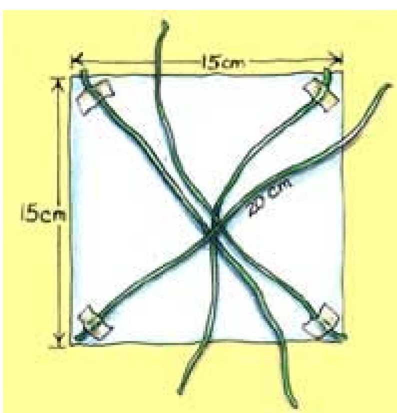
Airness Awareness!

A good example that shows that air is really "stuff" is the way a parachute works. After doing the activity, think of the problems a parachute would have if air really was just empty nothingness.

You will need:

- lightweight plastic shopping bag
- scissors
- string
- tape
- 2 pennies
- metric ruler

1. Use your ruler and a pen to measure and draw a square on one side of your plastic bag so that each side of the square is 15 centimeters. Cut out the square.



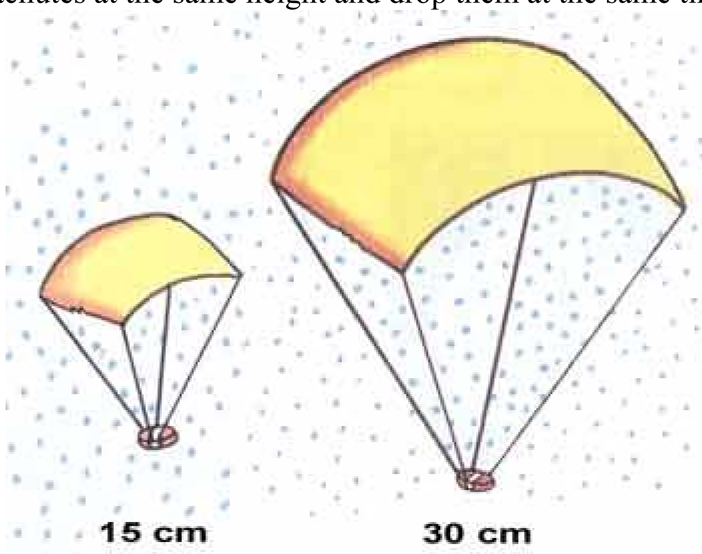
2. Cut 4 pieces of string about 20 centimeters long and tape them to the corners of the bag as shown.

3. Bring the free ends of the strings together and use tape to tape them to a penny so that you have a little parachute.

4. Hold the parachute from the middle of the square and drop it from high over your head. Describe how it falls. Why doesn't it fall really quickly like a stone? What do you think makes it float?

5.Use the other side of your bag to make another parachute that is 30 centimeters long on each side. Do you think this parachute will fall faster or slower than the smaller one? Why?

6. Hold both parachutes at the same height and drop them at the same time to see!



Think about this…

Look at the picture to the right. If air is made out of molecules of nitrogen, oxygen, argon, water vapor, carbon dioxide, and some other gases, how could you use this picture to explain why one parachute falls faster or slower than the other?

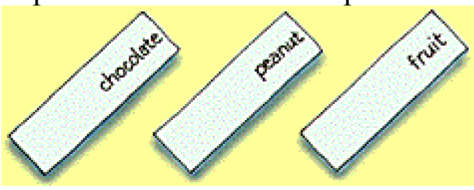
Appendix 17.2: Candy Chromatography
American Chemical Society. (2003, Nov. 17). *Candy Chromatography*. Retrieved February 15, 2006, from http://www.chemistry.org/portal/a/c/s/1/wondernetdisplay.html?DOC=wondernet\activities\color\candy.html

Candy Chromatography
Candy-coated chocolate, peanut butter, and fruit jellies come in many different colors in a pack. In the activity below you can check out the brown ones. Those brown ones may be more colorful than you think!

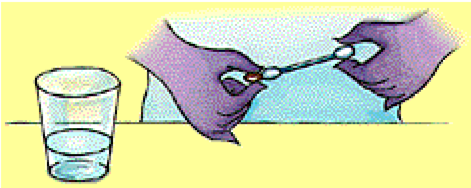
You will need:
candy-coated chocolate (brown)
candy-coated peanut butter (brown)
candy-coated fruit jelly (brown)
pencil
coffee filter (cone type)
cotton swabs
water paper or plastic cup (at least 7 oz)
blunt end scissors

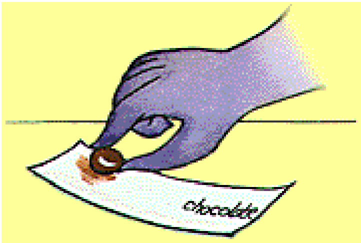
Activity

1. Cut three strips of coffee filter about 10 cm long and 3 cm wide. Write the name of each candy on a separate strip near the end of the strip.



2. Pour about cup of water into a cup. Dip one end of a cotton swab into the water and gently wet one side of a candy. Gently rub the candy's wet side onto its filter strip about 2 cm from the end to make a dark dot on the paper.





3. Repeat step 2 for your two other candies and paper strips, using a clean swab each time.

4. Carefully place your strips in the cup of water so that only a small portion of the bottom of each strip touches the surface of the water. Be sure that each dot is above the surface of the water. Bend the rest of the strip over the rim of the cup to keep it in place.

5. Observe each strip as the water moves up through the dot. What do you notice happening? Was the brown color on the candies a mixture of other colors? What are these other colors? Compare the colors used in each candy. In what ways are they the same or different?
6. Check the ingredients listed on the candy wrapper to see if the colors you now see match the ones used to color the candies!

Think about this

Here's another separation sensation! Put one drop each of two different food colors in a cup so that they mix. Use a cotton swab to soak up the color mixture. Place a dot of the color on a strip of coffee filter. Use chromatography the way you did in *Candy Chromatography* to see what happens.

Appendix 17.3: Chemistry and Color…it's a natural!
American Chemical Society. (2003, Nov. 17). *Chemistry and Color…it's a natural.* Retrieved February 15, 2006, from http://www.chemistry.org/portal/a/c/s/1/wondernetdisplay.html?DOC=wondernet\activities\color\natural.html

Chemistry and Color… it's a natural!

There are lots of colorful substances in nature that can change their color with the help of a little chemistry. Try the ones in the activity below!

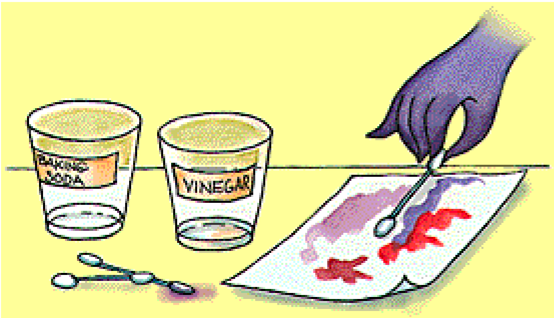
You will need:

grape juice
red carnation
red cabbage leaves
radish
vinegar
baking soda
measuring spoons
water
white unlined paper
cotton swabs
clear plastic cups
masking tape
pencil

Activity

1. Add 1 teaspoon of baking soda to 3 tablespoons of water in a cup. Label this cup baking soda.

2. Pour a little vinegar into a cup and label this cup "vinegar".
3. Use the cotton swab to paint a picture with the grape juice. Add more color to your picture by rubbing the flower petals and other plant parts onto the paper.
4. Paint over your picture with the baking soda solution. What happens to the colors in your picture? Now paint over your picture with the vinegar. What do you see happening?



Think about this

You could do some secret writing with your chemical color changers! Rub a red cabbage leaf, a radish, and a red carnation petal on a piece of paper. Use a small white candle to write a message on the colors. Dip a cotton swab into a baking soda solution and wipe it over the colored area. Your secrets are revealed!

Appendix 17.4: Colors on the Move

American Chemical Society. (2003, Nov. 24). *Colors on the move.* Retrieved February 15, 2006, from http://www.chemistry.org/portal/a/c/s/1/wondernetdisplay.html?DOC=wondernet\activities\color\move.html

Colors on the Move

The following activity uses the movement of color in milk to give some hints about what type of milk it is. At one point, the color moves pretty fast so don't let it get *past-your-eyes!!*

You will need:

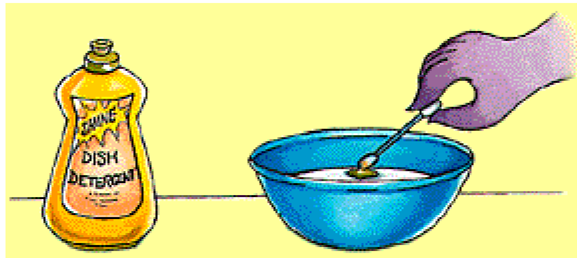
milk (skim, whole, and half & half)
3 shallow bowls
masking tape
pencil
liquid dish detergent
food coloring
cotton swab

Activity

1. Place three bowls on the table and label them **skim milk**, **whole milk**, and **half & half** as shown. Add about □ cup of skim milk, whole milk, and half & half to its labeled bowl. Look at the milks closely. What differences do you notice about them? What do you think might cause these differences?

2. Gently add one drop of food coloring to the center of the milk in each bowl. DO NOT STIR OR DISTURB THE BOWLS. What do you observe about the way the food coloring looks in each bowl? Does this observation make sense with what you observed about the milks before you put the food coloring in?

3. Dip a cotton swab in your detergent. Carefully touch the center of each food coloring drop in each bowl. Do not stir. Use a different cotton swab tip for each bowl. What do you observe? Do you notice a difference in the way the color looks in the different bowls? What do you think might cause these differences?



Think about this...

Color was useful in telling the difference between the different kinds of milk. Do you think it could help you tell the difference between fresh water and salt water? Place about □ cup of water in each of two separate clear plastic cups. Add about 1 tablespoon of salt to one of the cups and stir until no more salt will dissolve. Allow the water to sit for two or three minutes until it is still. Add one drop of food coloring to the center of the water in each cup. What do you observe? Does the color act differently in the two liquids? Could it help you tell them apart?

Appendix 17.5: Lose the Blues with CO2!
American Chemical Society. (2003, Nov. 17). *Lose the Blues with CO2.* Retrieved February 15, 2006, from http://www.chemistry.org/portal/a/c/s/1/wondernetdisplay.html?DOC=wondernet\activities\atmosphere\co2.html

Lose the Blues with CO2!

Carbon dioxide (CO_2) is essential for life on Earth. Scientists have ways of testing the amount of CO_2 in the atmosphere. In the activity below, you can do your own test for CO_2!

You will need:

- Red cabbage leaves
- Zip-closing plastic bag
- Water
- White piece of paper
- 2 clear plastic cups
- baking soda
- vinegar
- teaspoon
- tablespoon
- disposable plastic juice bottle (with wide mouth about ½ liter)

1. Tear up two leaves of red cabbage and place the pieces in a zip-closing plastic bag. Add about 3/4 cup water. Get as much air out of the bag as you can and close the bag securely.
2. While holding the bag, use your other hand to squish the leaves in the water until the water turns a medium to dark blue. This is your indicator solution. It will change color when certain substances are added to it.
3. Place 2 clear plastic cups on a white piece of paper. Pour about 2 tablespoons of the blue indicator solution into each cup.
4. Place about 3 teaspoons of baking soda in the bottle. Add about 1 tablespoon of vinegar. Hold your hand gently over the top of the bottle and swirl to mix the vinegar and baking soda which should produce bubbles of carbon dioxide (CO_2) gas.

5. Very carefully tilt the bottle over one cup so that only the CO_2 pours out of the bottle and into the indicator. Be sure that none of the liquid pours into the cup. The CO_2 is invisible, but since it is heavier than air, it should pour out of the bottle and into the cup of indicator.
6. Use a straw to stir the indicator solution in both cups. What did you notice? What must have caused the change you observed?

Think about this

If the indicator solution changes color when CO_2 is mixed in with it, what do you think would happen if you used a straw to bubble your own breath into some fresh red cabbage indicator solution? Try it and see!

Appendix 17.6: Chemistree

Chemist's Tree Ornament

Green Chemistry Institute, gci@acs.org
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Introduction

To celebrate the ChemisTree theme of Chemist's Celebrate Earth Day, many people will be planting trees. Trees, like all living things, are made of chemicals, but this relationship is probably not the first thought that comes to mind when one looks at a tree. Students can learn more about chemists who have made significant contributions to the environment by designing ornaments that celebrate these accomplishments and hanging them on the ChemisTree.

Associated Chemistry Topics

- History of Chemistry

Background

With so many chemists in the world, the hardest part of this activity will be selecting the chemists that will be represented on the ornaments. Green chemists are an excellent choice, since they strive to keep their chemical processes from negatively impacting the biological environment. Many green chemists work with renewable resources, including trees. Still other chemists, phytochemists, work to find chemicals within plants that can be beneficial to humans. Such chemicals usually include medicinals, herbicides, and insecticides. Web searching will lead you to chemists' names that are involved in these areas. Another search alternative would be to look at the faculty list of chemists at colleges and universities within your state. Chemists to include in this activity may be working in Environmental Science and Botany departments. They usually list a few things they like to research.

Materials

Colored Paper
Index cards or provided Student Worksheet
Hole Punch
Ornament hooks (bent paper clips, string, and yarn also work)
Scissors
Colored writing instruments
Internet or Library
Glitter
Glue
Tree

Procedure

1. Discuss the types of chemists who are involved in studying the earth. Try to narrow in on a type of chemist you want to recognize for earth day.
2. Have the students research to find the chemist they want to feature. On an index card, have each student write down 1) the name of a chemist, 2) the type of chemistry (s)he does, 3) a sentence or two about how their research relates to the Earth Day theme, 4) their name, 5) class period, and 6) instructor's name. You may wish to notice that this information is complete and that the choice is appropriate before students proceed to the creative portion of the activity.
3. Students are now ready to begin making their ornaments. They may want to make a rough draft of the ornament before using colored paper. The ornaments should be big enough to hold the chemist's name on one side, and the area of research on the other side. The ornaments should be small enough so that the class set can fit on the tree you will be decorating. Also, remind students that they need to leave room for a hole to be punched at the top.
4. Encourage students to be creative. Chemist's names can be stylized or colored. The ornament shape can look like an element from the periodic table, a plant, or can be colored like the planet. The research area can be represented by symbols as well as words.
5. Once they are done writing and drawing, the students may wish to glue yarn or glitter around the ornament's edges. Remind them not to use too much glue or it wont be able to be hung right away.
6. Have the students hole punch the top of the ornament and tie yarn through the hole so that it can hang from the tree.
7. Students that finish early should work on the Earth Day word search. When the class is done making their ornaments, each student should come to the front of the class to tell their peers which scientist they choose and why. After each student is done presenting, (s)he should hang the ornament (s)he made, and hand in their index card for assessment.

Questions

1. What scientist did you choose?
2. How does his/her research relate to the Earth Day theme?

Instructional Notes

Grade Level (Target Audience): ***3-5***

Estimated Time of Activity: ***One to two class periods***

Materials

Per Student:
Colored Paper
Index card or provided Student Worksheet
Ornament hook (bent paper clip, string, and yarn also work)
Internet or library access

Per Group (4-5 students):
Hole Punch
Scissors
Colored writing instruments
Glitter
Glue
Tree

Considerations and Adaptations

Considerations**:** To keep this activity at one 45-60 minute session, it may be helpful to provide a list of scientist to choose from to minimize the research time, or do not ask the students to present their work. For a two- class period activity, the students should research and begin a draft of the ornament during the first hour. For the second hour, begin by letting students know that they have a half hour to finish their work before presentations (assuming one minute presentations in a class of 30). Both the ornament and the presentation can be graded. It is easy to check off grading criteria on the ornament if you instruct the students to bring you their ornament to show you it is ready to be presented. It is helpful (especially if following directions is an issue in your class) to have the students show you the information they plan to use before they begin the art portion of the activity.
Less Advanced: K-2 will enjoy the art portion, but have difficulty with the research. A list of appropriate scientists is attached. Assign a scientist to each student. Do not ask your students to present to the class if their maturity levels do not permit successful presentations.
More Advanced: Sixth grade and higher may want to focus more on the research portion and less on the art portion. The week before Earth Day, take students to the library. Assign (as homework) a one-page essay where the students write a biography about the scientist they choose. On Earth Day, the students may spend half the class period making an ornament, and half the class period presenting the information in their essay.

Answers to Questions

Questions are open-ended and depend on the scientist chosen. This activity may be graded on the following criteria: 1) Scientist is appropriate for Earth Day, 2) creativity is shown, and 3) all information is complete. To grade presentations use the following criteria: 1) Scientist's name is mentioned, 2) how scientist relates to Earth Day is explained, and 3) students speak clearly and audibly.

References:

The History of Chemistry: 1992 Woodrow Wilson Summer Institute
http://www.woodrow.org/teachers/chemistry/institutes/1992/

CHF's Image Archives: Preserving Our Visual Chemical Heritage
http://www.chemheritage.org/OthmerLibrary/PictorialCollection/pictor.htm

MSU Chemistry- Chemical Genealogy http://www.cem.msu.edu/chem_gene.html

EPA Presidential Green Chemistry Challenge- Past Award Entries and Recipients
http://www.epa.gov/greenchemistry/past.html

Worksheet for Chemistree ornament:

Student Worksheet

Name__________________________

Directions: Design an ornament for the Chemist's Tree to honor a chemist whose work relates to the Earth Day theme.

Get your teacher's approval on your choice of scientist before you begin your ornament (hand your teacher the bottom portion of this work sheet to initial and give back to you). You may want to make a rough draft of the ornament before using colored paper. Some things you should consider:

- The ornaments should be big enough to hold the chemist's name on one side, and the area of research on the other side.
- The ornaments should be small enough so that the class set can fit on the tree you will be decorating.
- You need to leave room for a hole to be punched at the top.

Be creative! Chemist's names can be stylized or colored. The ornament shape can look like an element from the periodic table, a plant, or can be colored like the planet. The research area can be represented by symbols as well as words. You may wish to glue yarn or glitter around the ornament's edges. Do not to use too much glue or it wont be able to be hung right away.

Hole punch the top of the ornament and tie yarn through the hole so that it can hang from the tree.

If you finish early, work on the Earth Day word search.

When the class is done making their ornaments, each student will come to the front of the class to tell their peers which scientist they choose and why. After you are done presenting, you should hang your ornament.

Don't forget to hand in the bottom of this worksheet for your grading assessment.

Your name____

Teacher________________________________ Class Period __________

Name of a chemist ____

The type of chemistry (s)he does__________________________________

A sentence or two about how their research relates to the Earth Day theme

____

____

____

____

____

____

A list of chemists suggested for use in the Chemist's Tree Ornament Activity
Recipients of the ACS Award for Creative Advances in Environmental Science and Technology sponsored by Air Products and Chemicals, Inc. in memory of Joseph J. Breen
1980 James J. Morgan (aquatic chemist at CalTech) 1981 Philip W. West (Chair in air quality, environmental analytical chemistry at Louisiana State University) 1982 Jack G. Calvert (Atmospheric Chemistry Division at the National Center for Atmospheric Research. His areas of focus: photochemistry and reaction kinetics of the reactive atmospheric gases, molecules, atoms and free radicals; mechanisms of atmospheric oxidation of the hydrocarbons; modeling of the transformations of atmospheric gases and the role that trace organic compounds play in these processes; the effects of trace gases on air quality.)
1983 F. Sherwood Rowland (University of Irvine. He identified that CFC's were responsible for the depletion of the ozone layer. Rowland's research became the foundation for the enacting of several laws regarding the manufacture of CFC's.) 1984 Julian Heicklen (Professor Emeritus of Chemistry, The Pennsylvania State University. He was the first person to explain the basic chemistry of photochemical smog.) 1985 Arthur Fontijn (Professor of Chemical Engineering, Rensselaer Polytechnic Institute. His research area includes high temperature reaction kinetics to lead to the development of more efficient, less polluting, power generating combustors (e.g. turbines, car engines, and rocket motors), waste incinerators, fire extinguishers, etc.) 1986 Eugene E. Kenaga (Toxicologist with industrial chemistry background. He authored book on organic insecticides.) 1987 Joseph C. Arcos (Professor Emeritus at the Tulane University School of Medicine.) 1988 A. Welford Castleman, Jr. (Professor of Chemistry at Penn State. He studies reactions of water clusters to unravel heterogeneous reaction mechanisms of environmental importance.) 1989 James G. Anderson (Atmospheric Chemist at Harvard. He studies catalytic processes in the atmosphere controlling global change of ozone; and works on the development of high-altitude, long-duration unmanned aircraft for studies of global change.) 1990 David M. Golden (Department of Mechanical Engineering at Stanford. His research interests include atmospheric chemistry modeling.) 1991 Ronald A. Hites (Analytical Chemist at the University of Indiana. His research focus includes the global scale transport of halogenated compounds; polychlorinated dibenzodioxins and dibenzofurans; and anthropogenic organic pollutants in the Great Lakes.) 1992 Glen E. Gordon (Department of Chemistry and Biochemistry at the University of Maryland at College Park. His research area includes analysis of airborne rare earth metals.) 1993 John H. Seinfeld (Professor of Chemical Engineering at Cal Tech. His research areas include atmospheric chemistry, aerosol, and global change.) 1994 Steven J. Eisenreich (Professor of Environmental Sciences, Rutgers University. His research interests include PAHs, PCBs, coastal atmosphere) 1995 Donna L. Bedard (Professor of Biology, Rensselaer Polytechnic Institute. Her research interests include: identification, and isolation of novel species that catalyze the oxidation or dechlorination of PCBs and characterization of novel biotransformation and catabolic pathways for the degradation and detoxification of PCBs; elucidation of microbially-mediated dechlorination of PCBs in aquatic sediments; application of molecular techniques to identify and characterize critical members of the microbial consortia responsible for reductive PCB dechlorination in anaerobic sediment; and development of methods for in situ bioremediation of PCBs in

aquatic sediments.) 1996 Donald H. Stedman (Department of Chemistry and Biochemistry, University of Denver. His research has focused on development and demonstration of new ways to measure air pollutants, including tail-pipe emissions.) 1997 Charles E. Kolb (Chemist at Aerodyne Research, Inc. His research interest includes atmospheric chemistry of iodine.) 1998 Mario J. Molina (Chemist at MIT. He discovered the hole in the ozone due to CFCs.) 1999 Terry F. Bidleman and James F. Pankow (Researcher at the Air Quality Research Branch of the Atmospheric Environment Service at Environment Canada and Head of the Department of Environmental Science and Engineering at Oregon Graduate Institute, respectively. They researched in the behavior of pesticides and PCBs in the atmosphere.) 2000 Radhakrishna M. Jayanty (Researcher at RTI International. He was awarded for his development of methods to detect and accurately measure air pollution.) 2001 Michael R. Hoffmann (Professor of Environmental Science at Cal Tech. His research includes research on the sources, fates, and control of reduced sulfur compounds in the environment, such as hydrogen sulfide, sulfur dioxide, mercaptans, thiophenes, and alkyl sulfides in natural and engineered systems.) 2002 Roger Atkinson (Professor of atmospheric chemistry at University of California at Riverside. His research deals with the atmospheric chemistry of organic compounds emitted from anthropogenic and biogenic sources, with the focus being on the kinetics, products, and mechanisms of the gas-phase reactions of OH radicals, NO_3 radicals and O_3 with volatile organic compounds (VOCs). 2003 John W. Birks (Professor of chemistry at University of Colorado. He works on the development of new, light weight, low power instruments for vertical profiling of chemical species in the troposphere using kites and balloons as "sky hooks.")

Green chemists that work with plant materials

Joe Laszlo and Dave Compton, of the National Center for Agricultural Utilization Research, Agricultural Research Service, USDA, developed Soy Screen, an UV sunscreen made from soy and an antioxidant found in rice and oat bran.

John J. Meister, of the Center for Forest Products Research, Inc. developed polymers and plastics from lignin (an abundant plant polymer) biomass.

Richard P. Wool, of the Department of Chemical Engineering, University of Delaware, develops adhesives and rubbers from plant oils and lignin, and hurricane-resistant roofing materials from plant fibers.)

Nancy W. Y. Ho, of the Laboratory of Renewable Resources Engineering, Purdue University, engineered yeast to make ethanol fuel out of the two sugars found in cellulose.)

C. Bastoli, employee of Novamont, helped develop starch-based biodegradable polymers used in films in sheets.

J. Lunt, at Mitsui Toatsu chemical company, helped develop a plastic called Polylactic Acid from lactic acid (by-product of corn fermentation).

Past Presidential Green Chemistry Challenge Awards Academic Winners

1996, Mark Holtzapple (Professor at Texas A&M University. He was awarded for converting waste biomass to animal feed, chemicals, and fuels.)

1997, Joseph M. DeSimone (Professor at University of North Carolina at Chapel Hill and North Carolina State University. He was awarded for his design of CO_2 surfactants.)

1998, Karen M. Draths and John W. Frost (Professors at Michigan State University. They were awarded for their use of microbes and renewable feedstocks in the synthesis of chemicals.)
1999, Terry Collins (Professor at Carnegie Mellon University. He was awarded for the development of TAML catalysts used in H_2O_2 oxidations.)
2000, Chi-Huey Wong (Professor at the Scripps Research Institute. He was awarded for the development of enzymes used in large-scale organic synthesis.)
2001, Chao-Jun Li (Professor at Tulane University. He was awarded for the development of transition metal catalysis in air and water.)
2002, Eric J. Beckman (Professor at University of Pittsburgh. He was awarded for his design of non-flourous, highly CO_2-soluble materials.)

Appendix 17.7: Green Chemist's Tree Worksheet

Green Chemist's Tree Word Search

Michele La Merrill, m_lamerrill@acs.org
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Introduction

This word search is a great introduction to green chemistry vocabulary.

Green Chemistry Principle:

See 12 Principles for a complete list.

Associated Chemistry Topics

- Environmental chemistry
- Phytochemistry

Vocabulary

Atom Economy: the percentage of atoms from the starting materials incorporated into the final product. One of the 12 Principles of Green Chemistry.
Benign: harmless, having no effect.
Biodegradable: capable of being broken down by plants or animals into smaller pieces.
Caffeine: a bitter stimulant found in tea trees leaves, cocoa plant pods, kola plant nuts, and guarana bush berries.
Catalysis: a change in the rate of reaction induced by a material that does not change after the reaction.
Catalyst: a substance that helps chemical reactions to occur but is not changed in the reaction.
Compost: decayed plant material.
Degradable: capable of being broken down chemically so that it is less complex.
Environment: the complex of physical, chemical, and biological factors that surround an individual or community.
Flavanoid: the largest group of plant chemicals researched because of their health benefits (antioxidative, antimicrobial, and anticarcinogenic). Dietary flavanoids are found in certain teas, wines, fruits, vegetables, nuts, seeds, roots, and chocolate.
Green Chemistry: designing chemical products and processes to reduce or eliminate the use or generation of hazardous materials.
Neem: a tree that produces its own insecticide to keeps bugs away from it.
Phytochemical: a chemical made by plants.
Prevention: the act of hindering, or keeping something from occurring.
Renewable: capable of being replenished within a short time through ecological cycles.
Safer: less threatening, harmful, or risky.
Sustainable: of, relating to, or using a resource in a way so that over time it is not overly diminished, or permanently damaged.
Starch: a molecule made of many linked sugars that is widely distributed in the vegetable kingdom and is stored in all grains and tubers.
Taxol: an anti-tumor drug from the Pacific yew tree, Taxus brevifolia.
Topotecan: an anti-tumor drug from the Chinese tree, Camptotheca acuminata.
Yew: a tree that produces a phytochemical useful in cancer treatment.

Definitions adapted from Merriam Webster online http://www.webster.com and Experiencing Chemistry at OMSI online http://www.omsi.edu/visit/chemistry/glossary.cfm

Materials

Word Search Activity Sheet
Pencil

Procedure

1. Search for the vocabulary words. They can appear across, down, diagonally, and even backwards.
2. When you find words, circle them with your pencil.
3. You may work in pairs, but make sure to circle all the words on your own paper to get full credit.

Quiz

1. Write down three vocabulary words you learned today.
2. Can you also write their definitions?

Instructional Notes

*Grade Level (Target Audience): **3-5***

Estimated Time of Activity: No more than 60 minutes, depending on skill.

Materials

Word Search Activity Sheet
Pencil

Considerations and Adaptations

Considerations**:** students may need to finish this activity as homework if sufficient class time is not available.
Less Advanced: a word search is provided that does not include diagonal words.

Appendix 17.8: Mini-lecture for primary students

GASSING UP WITHOUT AIR POLLUTION

By Kathryn E. Parent, k_parent@acs.org
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You've probably been to a gas station to get some gasoline for a car. Gasoline, a type of fuel, is what most cars use for energy. Just like you need food for energy, cars need fuel for energy. Without fuel, a car is pretty useless. You know this well if you've ever been in a car that ran out of gasoline.

You may have seen smoke or noticed a smell coming out of car exhaust pipes. The smoke and smell come from gases that are emitted when gasoline is burned. Some of these gases can cause problems in the atmosphere. One of the gases, sulfur dioxide, forms acid rain when it combines with water in the atmosphere. Another gas, carbon dioxide, can cause the climate to change. Chemists are working to find other kinds of fuels that don't harm the earth's atmosphere. One solution to this challenge is to get the energy more directly from plants, instead of gasoline.

Unlike humans and cars, plants make their own energy. Plants grow using just sunlight, water and carbon dioxide from the atmosphere. This makes plants a very good source of energy. In fact, gasoline is formed from plants. When plants die and are buried under mud and rocks, they slowly change into a mixture of fuels, including gasoline. It takes a very long time underground for a plant to turn into gasoline. Humans are using gasoline much more quickly than it is being made. We might run out of gasoline someday.

So chemists have considered using plants directly as a source of fuel. Chemists make a fuel called biodiesel from vegetable oil. Vegetable oil comes from plants that can be grown by farmers each year. Instead of waiting thousands of years for gasoline to be made, farmers and chemists can work together to make biodiesel in one year. Biodiesel can even be made from vegetable oil left over from making fries at fast food restaurants. In the process, garbage becomes fuel.

Remember the smell of the fumes from car exhaust? When you burn biodiesel, it smells like french fries! The exhaust fumes from gasoline not only smell bad, they are bad for the atmosphere. Many cars have devices called catalytic converters, to remove some of the exhaust fumes that are formed from burning gasoline. It is better to find ways to prevent those gases from forming in the first place.

Using biodiesel instead of gasoline produces less exhaust fumes. Biodiesel has more oxygen atoms in it than gasoline does, and the extra oxygen helps biodiesel to burn better. The fumes from biodiesel are also safer for the atmosphere – they won't cause acid rain or change the climate. Unlike burning gasoline, burning biodiesel does not emit sulfur dioxide. And burning biodiesel doesn't add more carbon dioxide to the atmosphere. The carbon dioxide released when biodiesel is burned is the same carbon dioxide the plants removed from the atmosphere as they grew.

Biodiesel is just one alternative fuel that can prevent air pollution in earth's atmosphere. You can prevent air pollution by using less gasoline. Instead of riding in a car, you might choose to walk, ride a bicycle or use public transportation. By the time you start driving, you may choose to buy a car that doesn't use gasoline for energy.

APPENDIX 18: GREEN CHEMISTRY REACTIONS FOR SECONDARY STUDENTS

Appendix 18.1:

Phytochemical Debate/Essay Activity

Green Chemistry Institute, gci@acs.org

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Introduction

Earth Day is a time to reflect on the interdependent roles of humans and the environment. The theme of ChemisTREE focuses on the connections between humans, chemistry and plants. This activity offers an opportunity to use writing or debate skills to investigate chemicals produced by plants, or phytochemicals. Information and references for taxol, camptothecin and azadirachtin are provided. These phytochemicals are used in medicine and agriculture, providing intriguing examples of the chemistry that goes on inside of trees.

Green Chemistry Principles **(See 12 Principles for a complete list.)**

- Renewable Feedstocks
- Designing Safer Chemicals

Procedure

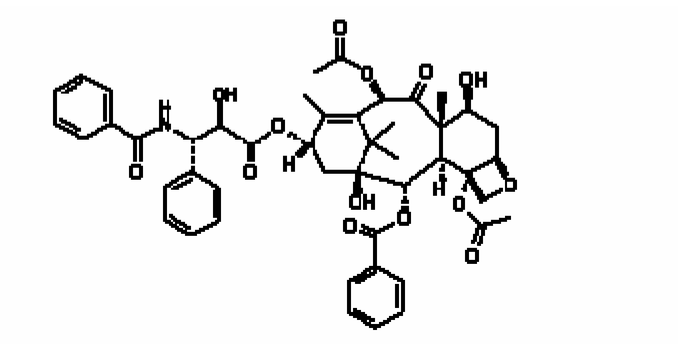
Compare and contrast the three examples of phytochemicals provided below.
Your discussion should include answers to the following questions:

- How was the drug discovered (who, what, where, when, why)?
- What is the primary chemical action of the drug?
- What is the medicinal or agricultural value of the drug?
- How will industrial production of the chemical be different than the natural production in the tree? Will that change your perception of the chemical's green chemistry status?
- Is using renewable feedstocks the same as designing safer chemicals? In other words, are plant-derived chemicals always safer than laboratory synthesized chemicals?

1. Taxol® (paclitaxel), an anti-tumor drug derived from the Pacific yew tree, *Taxus brevifolia*

For more information see these websites and articles:
http://www.bris.ac.uk/Depts/Chemistry/MOTM/taxol/taxol.htm
http://www.rti.org/page.cfm?objectid=0098D2DD-3FBE-4FD5-BAB462E2C7EE789C
Chemical & Engineering News, August 27, **2001**, *79*, 64-65.
http://pubs.acs.org/isubscribe/journals/cen/79/i35/html/7935books.html

Taxol Chemical Structure



Source: The American Society of Pharmacognosy
http://www.phcog.org/obits/Wall.html

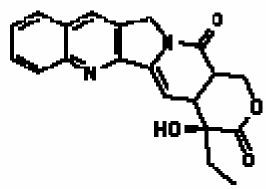
2. Camptothecin™ (CPT), an anti-tumor drug derived from the Chinese tree, *Camptotheca acuminata*

For more information see these websites and articles:

http://www.rti.org/page.cfm?objectid=0098D2DD-3FBE-4FD5-BAB462E2C7EE789C

Comins, D.L; Nolan, J.M. *Organic Letters*, 2001, 3, 4255-4257.

Camptothecin Chemical Structure



Source: The American Society of Pharmacognosy
http://www.phcog.org/obits/Wall.html

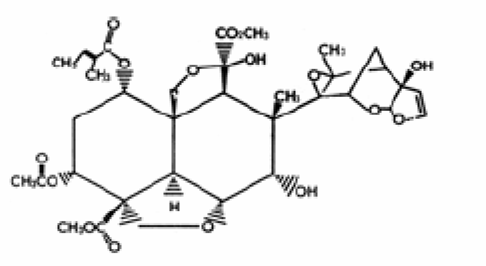
3. Azadirachtin, an insecticide derived from the Neem tree of South Asia, *Azadirachta indica*

For more information see these websites:

http://www.colostate.edu/Depts/Entomology/courses/en570/papers_1994/howatt.html

http://www.mhhe.com/biosci/pae/botany/botany_map/articles/article_33.html

Azadirachtin Chemical Structure



Source: Archer Landscape and Botanicals
http://user.gru.net/parker1/

Additional References

Goodman, J.; Walsh, V. *The Story of Taxol*, Cambridge University Press: Cambridge, UK, 2001.

Jew, S.; Kim, M.G.: Kim, H.-J.; Roh, E.-J.; Park, H. *Korean Journal of Medicinal Chemistry*, **1996**, *6*, 263-282.

National Research Council (US). *Neem - a tree for solving global problems.* National Academy Press: Washington, DC, 1992.
Schmutterer, H., Ed. *The Neem Tree*, VCH Weinheim, 1995.

Appendix 18.2:

FUEL CELLS:
ENERGY FROM GASES INSTEAD OF GASOLINE

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Introduction

Fuel cells transform chemical energy to electrical energy. They are used on space shuttles to generate electricity and water needed for the mission. Recently, fuel cells have been used to convert the air pollution generated during the treatment of wastewater into useful energy.

Green Chemistry Principle: Conserve Energy

Most of our current sources of energy are obtained from fossil fuels, such as coal, oil, and natural gas. Combustion of fossil fuels contributes to various forms of air pollution and produces carbon dioxide, a gas implicated in global warming. Furthermore, fossil fuels are not renewable resources. Recognition of both environmental and economic costs of energy production drives green chemistry research to find alternative, more sustainable sources of energy. Fuel cells are one type of alternative energy. Fuel cells offer several advantages over traditional energy sources, such as lower emissions of pollutants and greater efficiency.
(See 12 Principles for a complete list of green chemistry principles.)

Associated Chemistry Topics

- Energy
- Reduction-oxidation reaction
- Electrochemistry
- Atmospheric chemistry

Vocabulary

Aerobic – with oxygen present.
Anaerobic – without oxygen present.
Anaerobic Digester – a wastewater treatment process that uses microbes to reduce the amount of solid sludge waste; generates methane and carbon dioxide gases as byproducts.
Catalyst – a substance that helps chemical reactions to occur but is not changed in the reaction.
Electrodes – metal wires that provide electrical contact with an ionic solution and at which oxidation and reduction reactions occur.
Electrolysis – the use of electricity to cause a chemical reaction.
Electrolyte – a substance, often an ionic compound, which conducts electrical current through the movement of ions.
Fuel Cell – a device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity by an electrochemical process. If pure hydrogen is used as a fuel, fuel cells emit only heat and water as byproducts.[1] Also called a gas battery.
Green Chemistry – designing chemical products and processes to reduce or eliminate the use or generation of hazardous materials.
Oxidation – the loss of electrons, the gain of oxygen atoms, or the loss of hydrogen

atoms.
Redox Reaction – the complete reaction that occurs when a reduction and oxidation occur together.
Reduction – the gain of electrons, the loss of oxygen atoms, or the gain of hydrogen atoms.
Voltage – electrical potential, or tendency of electrons to flow, measured in units of volts (joule per coulomb).
Wastewater Treatment – the process of removing solids and other contaminants from sewage.

Reactions: Oxidation and Reduction

1. Electrolysis of Water: $2\ \mathbf{H_2O} \rightarrow 2\ H_2 + O_2$
2. Reduction of Oxygen: $\mathbf{O_2} + 4\ H^+ + 4\ e^- \rightarrow 2\ H_2O$
$\mathbf{O_2} + 2\ H_2O + 4\ e^- \rightarrow 4\ OH^-$
3. Oxidation of Hydrogen: $2\ \mathbf{H_2} \rightarrow 4\ H^+ + 4\ e^-$
4. Oxidation of Iron: $\mathbf{Fe} \rightarrow Fe^{2+} + 2\ e^-$
5. Oxidation of Methane: $\mathbf{CH_4} + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

Background

Energy consumption is a major issue in achieving a sustainable planet.
Historically, humans have used wood, coal, oil and natural gas for energy. Before the industrial revolution, wood was the primary source of energy for human activities. As technology developed, coal, oil and natural gas were used in place of wood. These three fossil fuels reflect a trend toward cleaner and more efficient fuels, as evidenced by the increasing ratio of hydrogen to carbon. Since the industrial revolution, society has depleted fossil fuels faster than the fuels are generated. Coal, oil and natural gas provide a lot of energy when they are burned. Yet, the combustion of fossil fuels is slowly changing the composition of the atmosphere, with climate change a probable outcome. Furthermore, fossil fuel extraction, refinement, and transport create many hazards in the workplace and the environment. These are drawbacks to the use of fossil fuels as an energy source.
Developing alternative sources of safer, cleaner, renewable energy is a goal of green chemistry. Converting the energy of the sun, wind or plants into a form suitable for human consumption is a challenge. A promising alternative to fossil fuels is fuel cell technology. Power from fuel cells is cleaner, generating less than 1% of the amount of pollution produced by traditional power production. Furthermore, methane gas, a byproduct of the decomposition of human waste (sludge), has been used in fuel cells to efficiently produce electricity. So fuel cells are doubly good for the earth, first by converting a byproduct into useful energy and second, by reducing pollution involved in making that energy.
First built more than 150 years ago, the fuel cell has much lower emissions than traditional combustion sources and is cheaper than solar power. A fuel cell is similar to a battery, constructed of two electrodes connected by an electrolyte (see **Figure 1**). In a hydrogen fuel cell, air (oxygen) and hydrogen gas generate heat, electricity and water by means of an electrochemical reaction.[2]

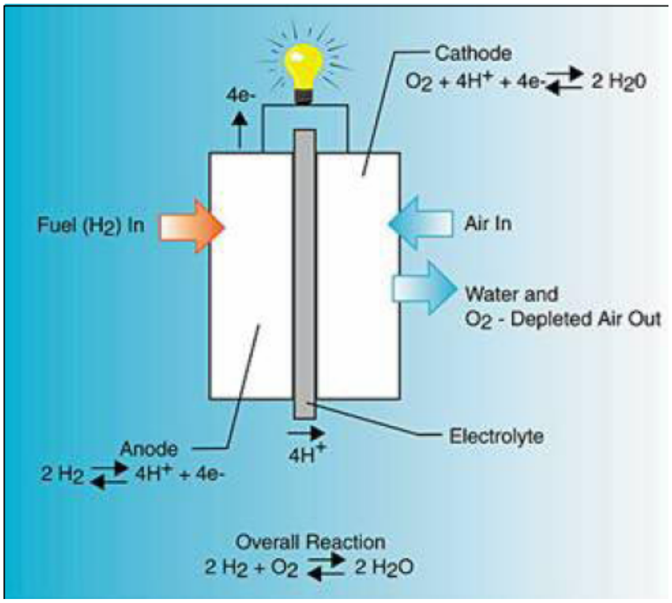

Figure 1: Diagram of a Fuel Cell
Source: Energy Types, "Fuel Cells and Hydrogen"
http://www.personal.psu.edu/users/m/e/mek183/energy_types.htm

The technology has the potential to increase energy efficiency, reduce greenhouse gas emissions and reduce air pollution compared with traditional combustion engines. Scientists expect fuel cells will be useful in a variety of personal devices ranging from automobiles and home furnaces to cellular phones. Fuel cells are still too expensive and experimental to be practical for widespread use. However, they are currently used to power city buses, NASA spacecraft and wastewater treatment plants.[3]

Fuel cell powered city buses are a technology on the ground, but with impacts on the quality of the earth's lower atmosphere. Several U.S. cities, including Chicago, IL; San Francisco, CA; and Washington, DC have fuel cell powered buses in operation in order to prevent air pollution associated with traditional combustion engines.
High-flying fuel cells are part of the National Aeronautics and Space Administration's (NASA) Environmental Research Aircraft and Sensor Technology (ERAST) program. The ERAST program aims to develop remote controlled flying vehicles to study the Earth's atmosphere.[4] NASA is currently developing fuel cell technology for uninhabited aerial vehicles (UAV). Fuel cells working together with solar cells offer electrical power during dark hours, less weight than battery systems and more reliability due to fewer moving parts. UAV are designed to provide atmospheric research, satellite relay, and news coverage of weather and natural disasters. The Helios Prototype UAV flew at a record-breaking altitude of nearly 100,000 feet. At this altitude, Earth's atmosphere is similar to the atmosphere of Mars. Fuel cell and UAV research will help NASA scientists design aircraft that can fly in the Martian atmosphere.
A more down to earth use of fuel cells has been developed at wastewater treatment facilities. These cells convert waste methane gas, or biogas, generated from sludge decomposition into useful electricity. The first successful use of biogas in fuel cells was in 1992 at a landfill demonstration test site in California. In 1997 the New York Power Authority installed the first commercial power plant to use this technology at a

wastewater treatment facility in Yonkers, NY. Since then the Columbia Boulevard Wastewater Treatment Plant in Portland, Oregon, has instituted fuel cell technology. The King County Wastewater Treatment Division of Washington State has begun building a fuel cell demonstration project, and a similar facility is in progress in Fukuoka, Japan. Other sites in the U.S. and Asia are currently using or planning to build fuel cell systems operating on waste gases from a variety of methane sources (landfills, hog farms, breweries).[5] The technology offers the opportunity to reduce operating expenses by providing electricity in a more efficient manner than a combustion generator, and make use of a waste byproduct of the treatment process. The earth's atmosphere benefits from the reduction of methane gas emissions.

Materials (per group of four)

- 2 platinum wires (3-4 inches long)
- 6 steel paper clips
- 3 plastic cups (8 ounce size)
- 400 mL beaker
- 250 mL vinegar
- 250 mL water
- 0.250 g Epsom salt
- 1 multimeter
- 1 battery (9 or 12 volt)
- 4 sets of alligator clips
- stopwatch
- ruler

Safety: This activity is intended for use by students in the laboratory under the direct supervision of a qualified chemistry instructor. The chemicals may be harmful if misused or if the procedures described are not followed. Wear gloves and goggles offering indirect splash and impact protection. Follow responsible chemical safety guidelines. This experiment involves the use of electricity. Care must be taken to avoid electric shock.

Procedure

1. Prepare the Epsom salt solution in the 400 mL beaker by dissolving the 0.250 grams of salt in 250 mL of water.
2. Fill each of the three plastic cups with 250 mL of one of the following aqueous solutions (be sure to label them):
(a) Water
(b) Vinegar
(c) Epsom salt solution
3. Measure the voltage of the water sample using the platinum wires for the electrodes. See **Figure 2** for assistance. The electrodes should be about 1 cm apart or closer, but not touching. Record the distance between the electrodes and make sure to use the same distance for all the samples.

Figure 2: Photo showing how to measure the voltage of a solution
Source: Courtesy of Dr. Martin Schmidt, "Platinum Fuel Cell Kit Instructions"
http://www.geocities.com/fuelcellkit/pdf/FC1101e.pdf

4. Set up the multimeter, alligator clips, battery, platinum electrodes and sample water solution in a circuit as shown in **Figure 3**. Always attach the battery last, and never let the electrodes touch each other.

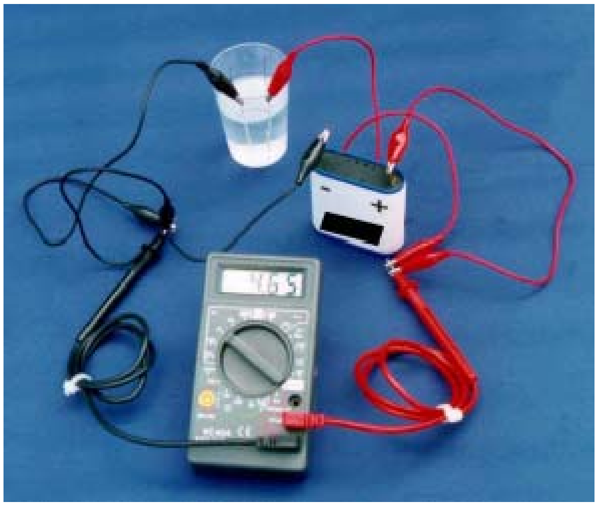

Figure 3: Photo of Electrolysis Experiment Set Up
Source: Courtesy of Dr. Martin Schmidt, "Platinum Fuel Cell Kit Instructions"
http://www.geocities.com/fuelcellkit/pdf/FC1101e.pdf

5. Record the voltage, and describe your observations.
6. Disconnect the battery, being careful not to disturb the solution or electrodes, record the voltage and start the stopwatch. Record the voltage and any other observations every 15 seconds for three minutes. After three minutes, record the voltage (and observations) every 30 seconds for three more minutes.
7. Repeat steps 3-6 for the two other samples. Be sure to thoroughly rinse the electrodes with water between each sample. For accurate comparisons, be sure to maintain a constant distance between the electrodes for all the samples.

8. Repeat steps 3-7 using straightened paper clips instead of platinum wires for electrodes. Be sure to use a new paper clip for each sample.
9. Summarize your data and observations in a table for each of the samples and the two types of electrodes. Be sure you have all the data you need to answer the following questions.

Questions

1. Write the names and formulas for the chemicals present in each of the aqueous samples.
2. What are the concentrations of the vinegar and Epsom salt solutions? Report concentration both in units of % (w/w) and Molarity (mol/L).
3. Write the balanced redox reaction that occurs when the battery is disconnected from the platinum wires for either the vinegar or Epsom salt sample. Which chemical species undergoes oxidation and which undergoes reduction?
4. Write the balanced redox reaction that occurs when the battery is disconnected from the paper clips for either the vinegar or Epsom salt sample.
5. What product forms on the surface of the steel paper clip while the battery is connected? (Hint: steel contains iron)
6. Graph the voltage versus time you recorded in step 6 of the procedure for each of the samples.
7. List the solutions in order of increasing final voltage observed in step 6. Explain the physical and chemical significance of the order. [Hint: look up the dissociation constant and reduction potential for the electrolyte species.]
8. Using the final voltage you recorded for the Epsom salt solution in Step 6, and assuming a current of 0.01 milliamps, calculate how many of these fuel cells it would take to power a 100-Watt light bulb. (Hint: Watt = Volt * Amp)
9. Most fuel cells kits cost over $200, and fuel cells used in wastewater treatment plants, vehicles and space shuttles cost even more. What are some of the differences between this laboratory demonstration fuel cell and a fuel cell used to power an automobile?

Instructional Notes

Grade Level (Target Audience): high school
Estimated Time of Activity: 2 hours

Materials (per group of four)

- 2 platinum wires (3-4 inches long)
- 6 steel paper clips
- 3 plastic cups (8 ounce size)
- 400 mL beaker
- 250 mL vinegar
- 250 mL water
- 0.250 g Epsom salt
- 1 multimeter
- 1 battery (9 or 12 volt)
- 4 sets of alligator clips
- stopwatch
- ruler

Safety: This activity is intended for use by students in the laboratory under the direct supervision of a qualified chemistry instructor. The chemicals may be harmful if misused or if the procedures described are not followed. Wear gloves and goggles offering indirect splash and impact protection. Follow responsible chemical safety guidelines. This experiment involves the use of electricity. Care must be taken to avoid electric shock.

Platinum wires are available from most chemical suppliers. In spring of 2003, prices ranged from $16 to $99, depending on the size of the order and wire specifications. Other sources include:
a) Hoffman electrolysis apparatus electrodes
b) Dr. Martin Schmidt (URL: http://www.geocities.com/fuelcellkit/offer.html). A set of electrodes is $29.90, or 10 sets for $149.90.

Considerations and Adaptations

Considerations: Students will need a copy of the original labels for Epsom salt and vinegar, or another source of the chemical names and formulas to answer Questions 1 and 2. Figure 2 may cause confusion due to the orientation of the alligator clips in the left-hand connection. The connection on the left is identical to the one on the right. Students may need help elucidating the reactions that are occurring at each electrode, especially the oxidation that occurs on the paper clip.

Less Advanced: The general principles of a fuel cell may be shown by a demonstration instead of the full laboratory activity. Alternatively, have students read articles (scientific journals, popular magazines, newspapers) about fuel cells and discuss the science, economics and policy. Some are of the opinion that fuel cells are the obvious energy source for our sustainable future. Others believe that ultimately fuel cells merely offer the same nonrenewable fossil fuel energy at a much higher cost. One issue at the heart of fuel cell technology is the source of hydrogen. Research is being done using methanol (CH_3OH), methane (CH_4) and hydrogen (H_2) as the hydrogen source.

Compare and contrast each fuel source in terms of source of fuel (and whether it is renewable), production, handling safety, waste emissions (include the chemical reactions), cost, and compatibility with existing fuel distribution systems. Draft a recommendation for funding research focused on the use of one of the three fuels, explaining your reasons for choosing that particular fuel over the other two.

Suggested articles:

Chemical and Engineering News "New fuel cells run directly on methane" (August 16, 1999, page 7):
http://pubs.acs.org/cgi-bin/bottomframe.cgi?7733notw7

The New Republic "Why Bush's H-car talk is just hot air" (February 24, 2003):
http://www.tnr.com/doc.mhtml?i=20030224&s=easterbrook022403

Society of Automotive Engineering, International, "Fuel Cells Start to Look Real"
http://www.sae.org/automag/features/fuelcells/index.htm

More Advanced: A high school AP chemistry laboratory, "Determination of the Fundamental Electronic Charge via the Electrolysis of Water" (*J. Chem. Educ.* **2000**, *77*, 95-96) offers a more challenging hands-on experience designed to reinforce the concepts of gas laws and stoichiometry.

Answers to Questions

1. Write the names and formulas for the chemicals present in each of the aqueous samples.
(a) Water = H_2O
(b) Vinegar = H_2O and CH_3COOH or $C_2H_4O_2$ (acetic acid, partially dissociates into CH_3COO^- and H^+)
(c) Epsom salt solution = H_2O and $MgSO_4$ (magnesium sulfate, dissociates into Mg^{2+} and SO_4^{2-})
2. What are the concentrations of the vinegar and Epsom salt solutions?
• Vinegar is 5% (w/w) acetic acid (30.06 g/mol) or 5.00 g in 100 mL of water. This is the equivalent of a 1.66 Molar solution (mol/L).
• The Epsom salt ($MgSO_4 \cdot 7H_20$ = 246.52 g/mol) solution is 0.250 g in 250 mL of water or a 0.1% (w/w) solution. This is the equivalent of a 0.00406 Molar solution (mol/L) or 4.06 mM.
3. Write the balanced redox reaction that occurs when the battery is disconnected from the platinum wires for either the vinegar or Epsom salt sample. Which chemical species undergoes oxidation and which undergoes reduction?
• $2 H_2 + O_2 \rightarrow 2 H_2O$
• Hydrogen is oxidized.
• Oxygen is reduced.
4. Write the balanced redox reaction that occurs when the battery is disconnected from the paper clips for either the vinegar or Epsom salt sample.
• No reaction
5. What product forms on the surface of the steel paper clip while the battery is connected? (Hint: steel contains iron.)
• The paper clip turns black as iron in the steel is oxidized, first to iron hydroxide, $Fe(OH)_2$, which then further reacts to form iron oxide, Fe_2O_3. Use the oxidation/reduction equations provided to guide students toward the reaction of Fe^{2+} and OH^- to form $Fe(OH)_2$.
$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4 Fe(OH)_3 \rightarrow 2 Fe_2O_3 \cdot H_2O$ (rust) + $4H_2O$
6. Graph the voltage versus time you recorded in step 6 of the procedure, for each of the samples.
• Graphs will vary from student to student, but should show an immediate decrease, compared to the voltage observed while the battery was connected, followed by a gradual drop to relatively constant value by the end of six minutes.
7. List the solutions in order of increasing final voltage observed in step 6 of the procedure. Explain the chemical significance of the order.
• The voltage for the Epsom salt solution should be higher than that for the vinegar solution because the salt is a strong electrolyte and dissociates completely, while the vinegar is a weaker electrolyte that dissociates to a much lesser extent. The plain water solution will have a very small, if any, voltage since there is no electrolyte present. The distance between the electrodes will also affect the observed voltage, and may disrupt the expected trend.
8. Using the voltage you recorded at three minutes for the Epsom salt solution in

Step 6, and assuming a current of 0.01 milliamps, calculate how many of these fuel cells it would take to power a 100-Watt light bulb. (Hint: Watt = Volt * Amp)
Given: 1V * 0.01 mA * 1A/1000mA = 2×10^{-5} W
It would require five million (100W / 2×10^{-5} W = 5×10^{6}) of these simple fuel cells to provide 100W.
9. Most fuel cells kits cost over $200 and fuel cells used in wastewater treatment plants, vehicles and space shuttles cost even more. What are some of the differences between this laboratory demonstration fuel cell and a fuel cell used to power an automobile?
The main issue is the electrolyte and catalytic surface – these are much more advanced and larger in expensive fuel cells.

Web References:

12 Principles of Green Chemistry
http://chemistry.org/greenchemistryinstitute/principles.html
Collecting the History of Fuel Cells: A Smithsonian Research Project
http://americanhistory.si.edu/csr/fuelcells/
Discovering the principle of the fuel cell
http://www.geocities.com/fuelcellkit/
Encyclopedia.com
http://www.encyclopedia.com/index.asp
Environmental Protection Agency, Office of Research and Development, "The Fuel Cells in Our Future"
http://www.epa.gov/ord/archives/2002/march/htm/article1.htm
Fuel Cells 2000
http://www.fuelcells.org/
HowStuffWorks, "How Fuel Cells Work"
http://www.howstuffworks.com/fuel-cell.htm
Merriam-Webster Online
http://www.m-w.com/home.htm
National Fuel Cell Education Program: EcoSoul Fuel Cell Demonstration
http://www.nfcep.org/html/fuelcell/fuelcell.htm
U.S. Department of Energy, Energy Efficiency and Renewable Energy, "Fuel Cells: Fuel Cell Basics"
http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/basics.html

Endnotes:

1 U.S. Department of Energy, "Fuel Cells: Fuel Cell Basics"
http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/basics.html
2 The National Fuel Cell Education Program, EcoSoul's web site, "Fuel Cell Demonstration," offers a Macromedia Flash movie of a fuel cell in operation.
http://www.nfcep.org/html/fuelcell/fuelcell.htm
3 (a) Spiegel, R.J. and J.L. Preston. "Test results for fuel cell operation on anaerobic digester gas" *Journal of Power Sources* **2000**, *86*: 283-288.
(b) EPA Office of Research and Development, "The Fuel Cells in Our Future"
http://www.epa.gov/ord/archives/2002/march/htm/article1.htm
4 See NASA's web site for more information:
(a) http://www.dfrc.nasa.gov/Research/Erast/erast.html
(b) http://www.dfrc.nasa.gov/Newsroom/FactSheets/FS-020-DFRC.html
(c) http://www.dfrc.nasa.gov/Research/Erast/helios.html

[5] Fuel Cell 2000's Frequently Asked Questions Page
(a) http://www.fuelcells.org/fcfaqs.htm#landfill
Fuel Cell Energy Press Release
(b) http://www.fuelcellenergy.com/site/investor/press/releases/2001/01_25_01.html

Appendix 18.3:

Chemistry and Compost

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Introduction

Earth Day is a time to reflect on the interdependent roles of humans and the environment. The theme "ChemisTREE" for Chemists Celebrate Earth Day focuses on the connections between humans, chemistry and plants. In this activity you will explore that interaction by constructing a compost system and examining the biodegradability of various types of trash.

Green Chemistry Principles **(See 12 Principles for a complete list.)**

- Prevent pollution rather than clean it up afterward.
- Use renewable sources of material.
- Design materials to biodegrade.

Associated Chemistry Topics

- Properties of matter
- Scientific method
- Cycles
- Oxidation

Vocabulary

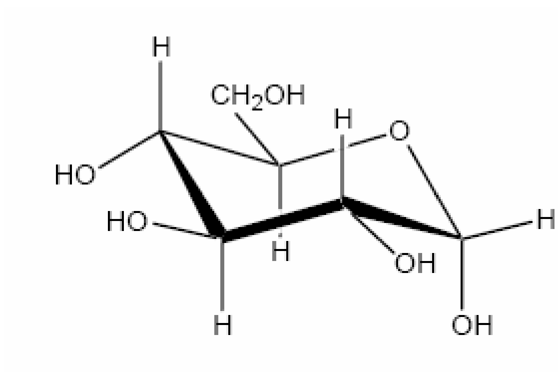
Aerobic – with oxygen present; typical of well-managed compost systems.
Anaerobic – without oxygen present; typical of landfills.
Biodegradable – capable of being broken down, especially into innocuous products, by the action of living things (as microorganisms). In soil, 90% of the organic carbon in a polymer must degrade into carbon dioxide within 180 days to be considered biodegradable by international standards for biodegradable plastics.
Cellulose – a molecule composed of glucose molecules (see **Chemical Structure 3**). Plants use this polysaccharide as a support structure in their cell walls. Cellulose is not easily broken down by human or animal enzymes.
Compost – a nutrient-rich mixture that consists largely of decayed plant material.
Glucose – a sweet, colorless, six-carbon sugar $C_6H_{12}O_6$ (see Chemical Structure 1). A carbohydrate referred to as a monosaccharide because it cannot be broken down into simpler units by hydrolysis reactions. The most common sugar in nature and the sugar most commonly fermented to ethanol.
Green Chemistry – designing chemical products and processes to reduce or eliminate the use or generation of hazardous materials.
Hydrolysis – a chemical reaction of a compound with a molecule of water.
Oxidation – the loss of electrons, the gain of oxygen atoms, or the loss of hydrogen atoms.

Oxidation of Carbon: $C + O_2 \rightarrow CO_2$

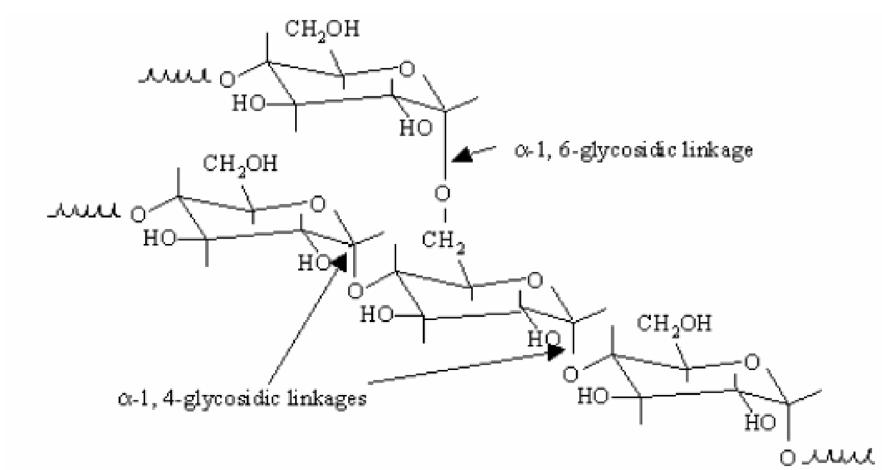
Polysaccharide – a large molecule composed of repeating sugar units; a carbohydrate that can be decomposed by hydrolysis into two or more monosaccharides.
Polystyrene – a plastic material composed of a polymer of styrene (see Chemical Structure 4); marketed under the trade name of Styrofoam®.
Starch – a polymer molecule composed of long chains of α-glucose molecules linked together (repeating unit $C_{12}H_{16}O_5$; see Chemical Structure 2). Plants store glucose for their energy needs in this polysaccharide. Starch can be easily broken down by human and animal enzyme systems. It is converted completely back into glucose via acid hydrolysis.

Chemical Structures

1. α-D-Glucose

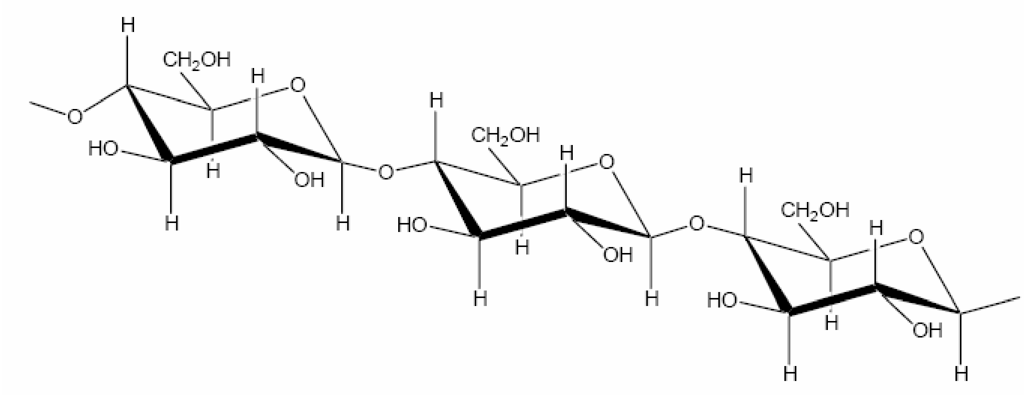


2. Starch

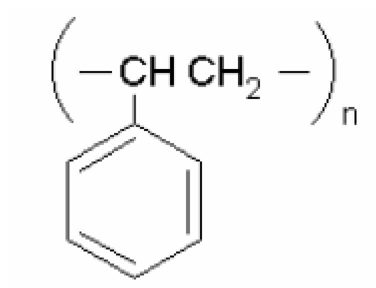


Source: Biofuels: Glossary of Terms for the Biomass Feedstock Composition and Properties Database
http://www.ott.doe.gov/biofuels/glossary.html

3. Cellulose



4. Polystyrene (Styrofoam®)



Background

Life on earth is based on cycles. Chemists and biologists study many different cycles. You may have studied the carbon, water, photosynthesis, or glycolysis cycles in your science classes. Figure 1 is a diagram showing the general cycle of carbon on the earth. Plants use carbon from the atmosphere to make glucose through photosynthesis. When plants die, the carbon dioxide is returned to the atmosphere through decay processes. Animals and humans return carbon dioxide to the atmosphere through respiration, and other human activities may capture or release carbon dioxide.

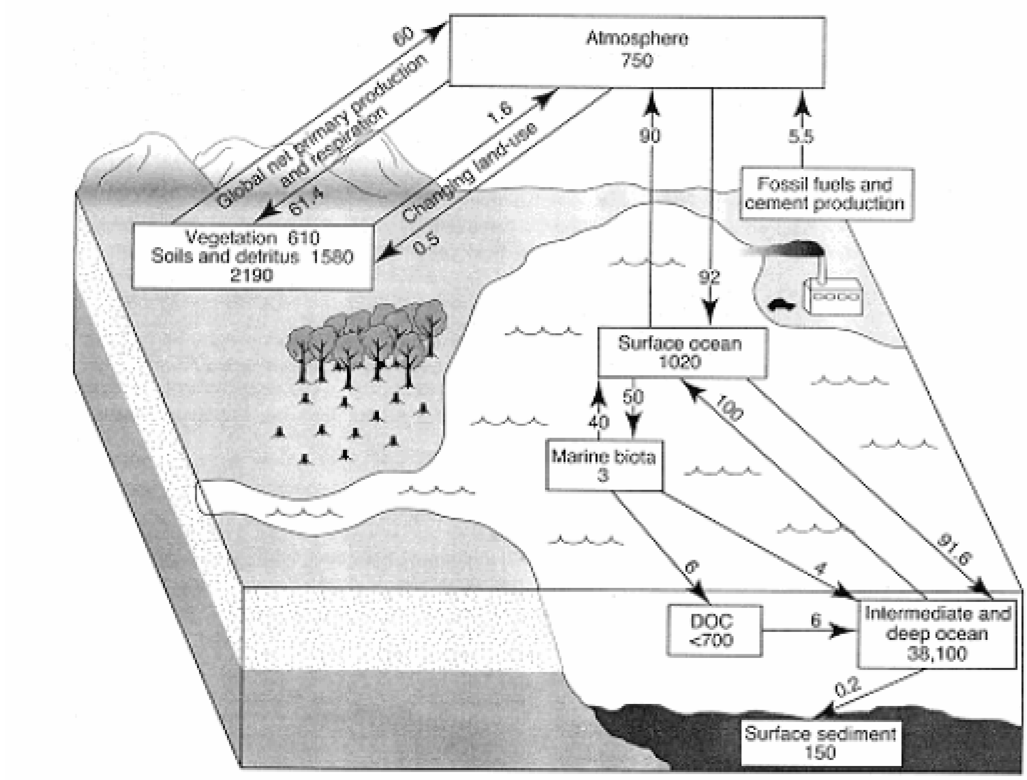


Fig. 1: The Carbon Cycle

Source: Carbon Cycle Diagram in gigatons of carbon (Gt C), http://www.whrc.org/science/carbon/carbon.htm

from Schimel, et al. 1995. CO_2 and the carbon cycle.

In: Climate Change 1994. Cambridge University Press: Cambridge, UK.

Over time, humans have learned that their activities impact the cycles in the environment. Materials do not always decompose, fuels are consumed faster than they are replenished, and wastes are generated that contaminate and compromise the cycles of the land, air and water. Cleaning up pollution involves a tremendous investment of time and energy. Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. In this way, chemists can design useful materials that are safe and environmentally friendly. By relying on renewable, bio-based materials and designing chemicals for degradation into benign substances, green chemistry is safeguarding the earth's cycles to ensure a sustainable future. Green chemistry has been described as "preventative medicine for the environment."[1]

Decomposition, often referred to as composting, is nature's way to recycle the energy and atoms in material that has passed its useful life. A compost system uses water, air and microorganisms to oxidize and break down, or biodegrade, complex materials into simpler elements and molecules. This process is very different from the landfill system, which attempts to isolate waste materials from water and air and prevent decomposition.

[1] Dr. Lynn Goldman, Assistant Administrator of Prevention, Pesticides, and Toxic Substances, Environmental Protection Agency (July 11, 1996).

The carbon atoms that are a part of starch molecules can be oxidized to carbon dioxide by the process of composting. Growing trees, like all photosynthetic organisms, can then use the carbon dioxide to build new starch molecules. The starch can later be harvested and made into useful materials. At the end of their life, the plant-based materials can be composted, returning the carbon atoms to the cycle.

This cycle of plant-based carbon is sustainable on a much shorter time scale than the cycle for petroleum-based carbon. Carbon enters trees from the atmosphere, and exits trees into the atmosphere, forming a complete cycle with no net increase in atmospheric carbon. However, petroleum was formed from plants that lived long ago, and when petroleum-based carbon is returned to the atmosphere, the net amount of carbon dioxide increases. The carbon in petroleum has been absent from the atmosphere for so long that it is no longer a part of the "cycle" as we know it.

By designing products from plant material, chemists can work with nature to produce safe and environmentally friendly materials. When the product is ready to be thrown away, these materials may be composted. The simpler decomposed material can then be reused, either in the ecosystem or in additional industrial applications.

ECO-FOAM® and NatureWorks™ are just two examples of new alternative packaging materials made from renewable plant material, starch, instead of petroleum-based chemicals. Plants store the majority of their energy in starch, which is simply sugar (glucose) units connected in a long chain (see Chemical Structures 1 and 2). Relying on starch to make packing materials means that the raw material can be grown each year from plants instead of being extracted from petroleum resources. Starch-based materials are also readily biodegradable because microorganisms can easily digest starch.

Materials

1. Four cups of prepared compost. If prepared compost is not available, a mixture of several different plant materials such as wood shavings, lettuce scraps, small wood chips, carrot peelings, newspaper strips, apple cores, pieces of paper egg cartons, bread crusts, chopped straw, banana peels, weeds, or grass clippings can be used.
2. Two containers to hold compost. Use available plastic cartons or make Soda Bottle Bioreactors. See the Cornell Composting Web Site: “Building a Soda Bottle Bioreactor” at http://www.cfe.cornell.edu/compost/soda.html for photos and instructions.[2]
3. Balance
4. Non-mercury thermometer
5. pH paper
6. Samples of waste material (i.e. paper, cardboard, plastic, Styrofoam®). Use what is available to you. The size or mass of the samples should be similar in order to make valid comparisons. Some examples are below:

[2] Authors: Nancy M. Trautmann, Tom Richard, Marianne E. Krasny, Patrick Cushing, Stephanie Hyson, Richard Northrup, Elaina Olynciw, Barbara Poseluzny

- Eco-film® biodegradable protective packaging film
- NatureWorks™ biodegradable plastic wrap

- Earth Shell® biodegradable food service packaging material
- ECO-FOAM® biodegradable, loose-fill packaging material
- Overhead projector plastic film
- Plastic grocery bag
- Plastic bubble wrap
- Polystyrene (or Styrofoam®)
- Newspaper
- Other paper or plastic waste materials of your choice

Procedure

1. Prepare enough containers or bioreactors to accommodate each of the different waste material samples. Be sure to label the containers appropriately, i.e. number each container and keep track of which waste material sample corresponds to which container number.
2. Divide the compost evenly between the empty cartons or bioreactors and record the mass of compost in each carton. Moisture in your compost will account for a significant portion of its mass; drier material will lead to greater experimental accuracy.
3. Cut the samples of waste material into the same approximate size that will fit into each container.
4. Record the mass of each sample of waste material and place each in a container with compost.
5. Be sure the compost is moist and is completely surrounding the sample. Be sure to record the mass of water you use to moisten the compost, though too much moisture will create anaerobic conditions
6. Write down the changes you think will occur to the waste materials – summarize your thoughts as a two-sentence hypothesis.
7. Prepare a table to record your observations over the next several weeks. Observations should include characteristics such as mass, temperature, pH, moisture, odor and overall appearance. Your table should include columns to record date, time and sample number. An additional column for miscellaneous observations may also be helpful.
8. Monitor the conditions (temperature, pH, moisture, odor, appearance) of the compost and the waste material over the next several weeks. You may need to add water occasionally to keep the compost moist; record how much additional water you added and the date and time when it was added.
9. Share your data with the other groups and collect the data from other groups. Be sure you have all the information you need to answer the questions below.
10. Analyze the class data to answer the following questions:

Questions

1. Describe the initial and final conditions of your cartons – composition, weight, temperature, pH, moisture, odor, appearance etc., of both the compost and the waste material sample.

2. What was your hypothesis? What is your conclusion based on the data you collected? Does your conclusion match your initial hypothesis? If not, account for the discrepancy. How do your results compare with those of the rest of the class?
3. Which sample of waste material changed the most? The least? (Make sure to describe the change in your answer.)
4. Summarize the similarities and differences between the structures, physical properties and biodegradability of starch, cellulose and polystyrene.
5. You are responsible for buying disposable packaging materials (bags, cups plates, etc) for your company. Choose two of the samples you composted and write a two-page report. A full analysis will include raw material source, production process, chemical structure, cost, performance characteristics and biodegradability of each of the samples. Conclude by justifying the purchase of one product instead of the other.

Instructional Notes

Grade Level (Target Audience): 8-12

Estimated Time of Activity:

Initial set up: 1-3 hours
Observation and data collection: 4-8 weeks
Write up: 2-4 hours

Materials (per group of four)

1. Four cups of prepared compost. If prepared compost is not available, a mixture of several different plant materials such as wood shavings, lettuce scraps, small wood chips, carrot peelings, newspaper strips, apple cores, pieces of paper egg cartons, bread crusts, chopped straw, banana peels, weeds, or grass clippings can be used.
2. Two containers to hold compost. Use available plastic cartons or make a Soda Bottle Bioreactor: See the Cornell Composting Web Site: “Building a Soda Bottle Bioreactor” at http://www.cfe.cornell.edu/compost/soda.html for photos and instructions.[3]
3. Balance capable of measuring the mass of the containers and compost (expect 500 g to 2 Kg)
4. Non-mercury, Celsius thermometer
5. pH paper
6. Two samples of waste material (i.e. paper, cardboard, plastic, Styrofoam®). Use what is available to you. The size or mass of the samples should be similar in order to make valid comparisons. Some examples are below:

- Eco-film® biodegradable protective packaging film
- NatureWorks™ biodegradable plastic wrap
- Earth Shell® biodegradable food service packaging material
- ECO-FOAM® biodegradable, loosefill packaging material
- Overhead projector plastic film

- Plastic grocery bag
- Plastic bubble wrap
- Polystyrene (or Styrofoam®)
- Newspaper
- Other paper or plastic waste materials of your choice

This procedure is very adaptable to available materials and time. Provide two waste samples and sufficient compost and containers for two bioreactors per group of four students. Have each group monitor their waste samples and then share their data with the class. (Sample data tables are provided in a separate document.)
3 Authors: Nancy M. Trautmann, Tom Richard, Marianne E. Krasny, Patrick Cushing, Stephanie Hyson, Richard Northrup, Elaina Olynciw, Barbara Poseluzny

Considerations and Adaptations

Considerations: This procedure is very adaptable to available materials and time. Depending on the level of the students, the number of group members and number of different samples can be adapted.
Less Advanced: For younger students, consider providing before and after samples rather than having them be responsible for composting their own samples. They can make observations on these two samples in one hour. Third through fifth grade students should be able to propose a hypothesis after you have introduced the activity.
More Advanced: For a more extended study, have students alter the conditions of the bioreactors, for example exclude oxygen by providing excess water, or decrease temperature by setting the samples on ice or in a refrigerator. Keep in mind it is difficult to analyze the results if more than two variables are being used, especially with the quantity of bioreactors being observed. Use of a computer program for analyzing the data is strongly encouraged.

Answers to Questions

The answers are specific to the individual samples.

References:

Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice, Oxford University Press: Oxford, UK, 1998.
Ryan, M. A.; Tinnesand, M., Eds. Introduction to Green Chemistry, Washington, DC: American Chemical Society, 2002.

Web References:

12 Principles of Green Chemistry
- http://www.chemistry.org/portal/resources?id=1edf9cd6e77911d6ecd56ed9fe800100

CORNELL Composting
- http://www.cfe.cornell.edu/compost/Composting_Homepage.html

Biofuels: Glossary of Terms for the Biomass Feedstock Composition and Properties

Database
 http://www.ott.doe.gov/biofuels/glossary.html
Encyclopedia.com
 http://www.encyclopedia.com/index.asp
Earth Shell®, biodegradable food service packaging material
 http://www.earthshell.com/
Eco-film®, biodegradable protective packaging film from Cortec
 http://www.vciplastic.com/bio_films.htm
ECO-FOAM®
 http://www.eco-foam.com/education.asp
 Classroom Activities: http://www.eco-foam.com/education.asp
Global Carbon Cycle - Woods Hole Research Center
 http://www.whrc.org/science/carbon/carbon.htm
Green Chemistry Institute
 http://chemistry.org/greenchemistryinstitute
KidTech, Magic Nuudle®
 http://www.magicnuudles.com/home.htm
 Ecology Lesson:
http://www.magicnuudles.com/lessonplans/Nuudle_ecology_LP.htm
Merriam-Webster Online
 http://www.m-w.com/home.htm
NatureWorks Plastic Packaging
 http://www.cargilldow.com/corporate/package.asp
Polystyrene Packaging Council Homepage
 http://www.polystyrene.org/index.html

Attached Worksheets:

Student Worksheet ***Name______________________***

Container Number	Sample Name	Date	Time	Temperature (degrees Celcius)	Mass (grams)	General Observations (pH, moisture, odor, appearance, etc)
1						
2						
3						
4						
5						
6						

Student Worksheet ***Name______________________***

Container Number	Sample Name	Date	Time	Temperature (degrees Celcius)	Mass (grams)	General Observations (pH, moisture, odor, appearance, etc)
1						
2						
3						
4						
5						
6						

Appendix 18.4:

Simple Green Uses Green Chemistry to Make Cleaning Possible

By Kathryn E. Parent, k_parent@acs.org

Introduction

Sunshine Makers has developed an entire line of environmentally safer cleaning products, trademarked under the name Simple Green®. The Simple Green® cleaning products incorporate a number of green chemistry principles. Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous materials. The principles of benign design, safer solvents, and pollution prevention are all incorporated into the design of this greener cleaning product.

These characteristics make Simple Green® a fitting example of green chemistry, in keeping with the theme for the 2002 National Chemistry Week, "Chemistry Keeps Us Clean."

Benign Design

Simple Green® products are designed to provide cleaning function with chemicals that are nontoxic and biodegradable. The surfactants, chemicals that remove soil and suspend it in water, in Simple Green® are designed to maximize effective cleaning while minimizing health and environmental impacts. The cleaners are a milder alternative to traditional cleaning products, with less impact on the user and the environment. The use of a water solvent provides a safer alternative to the volatile hydrocarbon solvents typically used to remove grease and oil.

Safer Solvents

Simple Green® uses water, one of the safest solvents known, as the major component of their cleaning products. The mild formulation is safer to use than traditional household cleaners like bleach (NaOCl) and ammonia (NH_3). The safer solvent system in Crystal Simple Green®, an industrial cleaner, eliminates the need for volatile chlorinated hydrocarbon solvents and caustic additives typically used to clean grease and oil from mechanical parts and electronics.

In spite of the rule -of-thumb "like dissolves like," Simple Green® is capable of washing away grease and oils that are usually not soluble in water. Rather than depending on the dissolving abilities of traditional organic solvents, Simple Green® utilizes the process of micelle formation to remove soil from a surface and suspend it in aqueous solution. Micelles, shown in **Figure 1**, are formed in water when chemicals with a hydrophilic (water loving) head and hydrophobic (water fearing) tail organize into spheres that orient the hydrophobic tails within the sphere. Simple Green® utilizes this type of chemical to remove grease or oil, which are also hydrophobic, from a surface and into the center of a micelle. The soil and the micelle are then washed away from the surface with the water of the cleaning solution. This process is able to essentially dissolve oil in water.

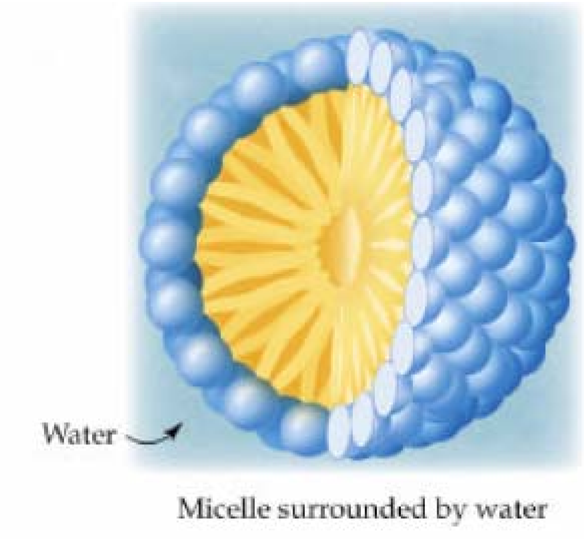


Figure 1: Diagram of a Micelle. A sphere with hydrophilic heads (blue) at the surface, and hydrophobic tails (brown) sequestered inside.
Source: Prentice Hall Media Library
http://cwx.prenhall.com/bookbind/pubbooks/mcmurrygob/medialib/media_portfolio/text_images/FG24_0302.JPG

Pollution Prevention

Simple Green® products target pollution prevention in a variety of ways, including waste reduction, design for degradation and reduced packaging. Crystal Simple Green® reduces toxic waste compared to traditional industrial cleaners. Organic industrial cleaners dissolve grease and oil into their hydrocarbon solvent. Then the volatile solvent is removed, a process that leads to air pollution. The subsequent oil sludge must then be disposed of as solid waste. The aqueous solvent system of Crystal Simple Green® eliminates the need for solvent removal, thus reducing air pollution and solid waste disposal. The waste that is generated by the cleaning process, a dilute mixture of grease and cleaner, can be treated safely and efficiently in a wastewater treatment plant because the cleaning chemicals are nontoxic and biodegradable.

Simple Green® is sold in a concentrated form so its strength is readily adjustable by the end user. This makes it widely adaptable to a variety of cleaning jobs. Packaging use is reduced to a minimum since each gallon of Simple Green® can provide up to 50 gallons of general cleaning solution; the packaging waste from 10 different cleaning products is reduced to one. In addition, the Simple Green® bottles are made of recyclable plastic, and since Simple Green® is non-toxic, the bottles can be rinsed out and used for many other purposes.

Simple Green® products provide an excellent example of how chemistry makes cleaning possible. The examples from Simple Green® also show how the application of green chemistry principles, such as benign design, safer solvents and pollution prevention, can be used to design an effective cleaning product that is safer for the user and the environment.

List of Links from Simple Green Article

Green Chemistry Institute
http://chemistry.org/greenchemistryinstitute
American Chemical Society
http://chemistry.org
Simple Green®

http://www.simplegreen.com/
National Chemistry Week
http://chemistry.org/ncw
Crystal Simple Green®
http://www.simplegreen.com/products/industrial/product2.html

Appendix 18.5:

BLEACHING WITH GREEN OXIDATION CHEMISTRY

By Kathryn E. Parent, k_parent@acs.org

Introduction

Whether you're washing the dirt off your face, cleaning grease from your hands or removing the stain on your shirt, chemistry is at work, helping you to remove unwanted dirt, grease and stain molecules. Keeping clean is often about removing color. In essence, stains are color where you don't want it. Stain 'removal' is usually decolorizing, or bleaching, not complete removal of the stain molecules.

Most likely when you hear the word 'bleach,' you think of Clorox® laundry and household bleach (1). The active ingredient in bleach, the chemical sodium hypochlorite, keeps your T-shirts white and your bathtub sparkling. If you've ever spilled Clorox® on something colored, you know it can also turn your favorite red sweater, white. Alternative "non-chlorine" bleaches are also available. They contain hydrogen peroxide instead of sodium hypochlorite.

The chemical hydrogen peroxide is also the bleaching agent in many hair dyes. Alone, peroxide gives the "peroxide blonde" color, but most permanent dyes use peroxide as well, either to remove natural dye in the hair or to activate the new dye (2).

Dilute hydrogen peroxide (3%) is also commonly found in medicine cabinets. It is used as an antiseptic for minor cuts and scrapes, and is also a good way to remove bloodstains from clothing. The bubbling that occurs when the peroxide encounters blood is due to its decomposition into oxygen gas and water (Eqn. 1).

$$H_2O_2 \rightarrow \tfrac{1}{2}\, O_2 + H_2O \quad \text{(Eqn. 1)}$$

During this process, hydrogen peroxide oxidizes the colored compounds in the blood.

Oxidation

Oxidation is most generally defined as losing electrons, and reduction is gaining electrons. The two processes occur together, so one compound is reduced in the process of oxidizing another compound. Another definition of oxidation is the gain of oxygen atoms (Eqn. 2) or the loss of hydrogen atoms. Reduction is then the loss of oxygen atoms or the gain of hydrogen atoms (Eqn. 3).

Oxidation of Carbon: $C + O_2 \rightarrow CO_2$ (Eqn. 2)

Reduction of Nitrogen: $N_2 + 3H_2 \rightarrow 2\,NH_3$ (Eqn. 3)

The color of compounds is a physical property caused by the chemical structure of the molecules. When an oxidizing agent removes electrons, or oxidizes, a molecule, the chemical structure of the molecule is changed and the physical property of color is altered. The decomposition of hydrogen peroxide involves the formation of free radicals. These reactive intermediates oxidize other molecules by removing electrons or hydrogen atoms from them.

Peroxide Activator Catalysts

The research conducted by Terry Collins' group at the Institute for Green Oxidation Chemistry at Carnegie Mellon University (3) provides a fitting example of green chemistry, in keeping with this year's theme for National Chemistry Week, "Chemistry Keeps Us Clean." Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous materials. The principles of benign design, selective catalysis, energy efficiency, and pollution prevention are all incorporated into the design of this greener bleaching agent.

Professor Collins has developed tetraamido macrocyclic ligands (TAML®) that, coordinated with a transition metal, effectively catalyze hydrogen peroxide oxidation (4). An example of a TAML® oxidant activator is shown in Figure 1.

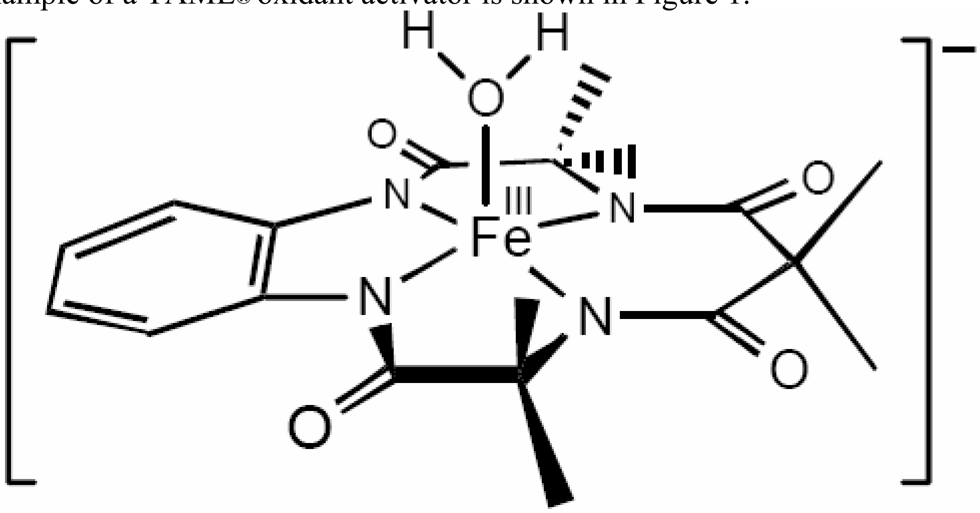


Figure 1: Structural example of a TAML® oxidant activator

His work received the Presidential Green Chemistry Challenge Award in 1999 (5). The TAML® oxidant activators offer an environmentally friendly alternative for chlorine-based bleaching processes. Made from natural biochemical elements, they are highly selective catalysts that reduce energy costs and not only prevent pollution, but are also useful in pollution remediation.

Motivation

In addition to common use as a household cleaner and hair dye, oxidative bleaching is also used in the pulp and paper, textile and laundry industries. Hydrogen peroxide (H_2O_2) is a greener alternative to chlorine (Cl_2), chlorine dioxide (ClO_2) and sodium hypochlorite (NaOCl) that are traditionally used for bleaching color from substances. In chlorine containing bleaches, oxidation often involves addition of chlorine atoms (rather than oxygen atoms) to the colored compound. For certain applications, the addition of chlorine leads to the formation of hazardous byproducts, such as dioxins, shown in Figure 2 (6).

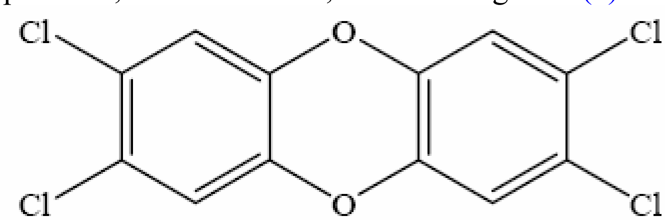


Figure 2: Structure of 2,3,6,7-tetrachlorodibenzo-4-dioxin

But hydrogen peroxide does not contain any chlorine atoms; it oxidizes by either adding oxygen or removing hydrogen atoms. Therefore, the oxidized compound cannot contain organochlorine type pollutants, and the problem of hazardous pollution is prevented at the source.

Challenges for Peroxide Bleaching

The challenge of replacing traditional bleaching agents with hydrogen peroxide is twofold. First, the peroxide oxidation process can be unselective. Since molecules exposed to

hydrogen peroxide might encounter free radicals, their destruction rather than the desired oxidation may result. Second, successful bleaching with H_2O_2 requires higher temperatures and pressures and longer reaction time. This means higher costs for energy, equipment and labor for the process. The TAML® oxidant activators were designed to meet both of these challenges.
To avoid uncontrolled destruction of molecules, the catalysts were designed to favor a different intermediate in the oxidation process. The catalysts form activated peroxides that are still very reactive, but much more selective than the free radicals formed during the normal decomposition of hydrogen peroxide.
By its nature, catalysis lowers the energy requirement for a reaction. Using the TAML® catalysts lowers temperature and time requirements for the bleaching process. For the pulp and paper industry, this adds up to huge energy savings. The TAML® oxidant activators have been skillfully developed over the past 20 years to optimize the oxidation of compounds by hydrogen peroxide.

Applications of TAML® Oxidant Activators

The cleaning applications of TAML® activators include bleaching the lignin in wood pulp (7), decolorizing the effluent from the pulp and paper and textile industries (8), and destroying free dye molecules in clothes laundering (9). Other practical applications in related areas are under investigation.
Lignin is a complex array of molecules that holds the cellulose in wood together. It is also responsible for the brown color of paper, like that used for paper grocery sacks. In order to get bright white paper, the lignin must be removed. The paper industry traditionally used chlorine for this purpose. In the past 10 years, most of the industry has moved to chlorine dioxide, which minimizes the formation of dioxins that result from chlorine treatment. Bleaching with TAML® activators and hydrogen peroxide offers another advance in the greening of the process, by completely eliminating the formation of dioxin waste.
Lignin is also responsible for the dark color associated with the effluent from paper mills. While the effluent from chlorine dioxide based delignification processes does not pose a high toxicity hazard, it is an aesthetic and environmental problem. TAML® activated peroxide treatment of the effluent removes most of the color, as shown by the photograph in Figure 3 (10).

Figure 3: 70% color reduction of paper mill effluent achieved using the TAML® activator and hydrogen peroxide.
TAML® activators have also been used with hydrogen peroxide to successfully decolorize the dyes in the effluent from textile mills. The photograph in Figure 4 (11) shows the significant removal of color achieved by the catalyzed oxidation.

Figure 4: Starting dye bath solution in dyeing jig (A), sample of dye bath solution after >90% of the dyestuffs have been transferred to the fabric (B), and the decolorized solution after using TAML® activator and hydrogen peroxide (C).

Very recently the TAML® technology has been applied to laundry. One of the challenges faced in reducing laundry water usage is the problem of dye transfer. The highly selective activator uses the peroxide present in some detergents to hunt and destroy free dye molecules, while leaving those dyes bound to fabric alone. You can wash your favorite red sweater with your bright white T-shirts and have both come out looking as good as new.

The catalysts developed by Professor Terry Collins and his colleagues at Carnegie Mellon University provide a superior example of the application of green chemistry to several practical cleaning and industrial processes. The principles of designing safer chemicals, using selective catalysis, improving energy efficiency, and preventing hazardous waste were applied in developing this greener chemical bleaching product.

References

(1) For more information about the science of Clorox® bleaching visit their Web Site: http://www.clorox.com/science/

(2) Raber, L. *Chem. Eng. News* **2000**, *78*(March 13), 52-53., and Raber, L. *ChemMatters* **2002**, *29*(April), 10-11.

(3) For information about the Institute for Green Oxidation Chemistry refer to the Web Site: http://www.chem.cmu.edu/groups/collins/about/index.html

(4) Collins, T. J. *Acc. Chem. Res.* **2002**, *35*, 782-790.

(5) Collins , T. J. "TAML® Oxidant Activators: General activation of hydrogen peroxide for green oxidation processes." In *The Presidential Green Chemistry Challenge Awards Program: Summary of the 1999 Award Entries and Recipients*; EPA744-R-00-001, U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics: Washington, DC, 2000; p 3.

For information about the Presidential Green Chemistry Challenge, refer to the Web Site: http://www.epa.gov/greenchemistry/presgcc.html

(6) Cann, M. C.; Connelly, M. E. *Real World Cases in Green Chemistry*, American Chemical Society: Washington, DC, 2000. See also the University of Scranton's Greening Across the Curriculum Web Site: http://academic.scranton.edu/faculty/CANNM1/inorganic/inorganicmodule.html

(7) Collins, T.J.; Hall, J. A.; Vuocolo, L. D.; Fattaleh, N. L.; Suckling, I.; Horwitz, C. P.; Gordon-Wylie, S. W.; Allison, R. W.; Fullerton, T. J.; Wright, L. J. In *Green Chemistry:*

Challenging Perspectives; Anastas P. T., Tundo P., Eds.; Oxford University Press: Oxford, **1999**, pp 79-105.
(8) Collins, T. J. *Acc. Chem. Res.* **2002**, *35*, 782-790.
(9) Collins , T. J. "TAML® Oxidant Activators."
(10) Horwitz, Colin. Personal Communication, 17 September 2002.
(11) Ibid.

Appendix 18.6:

CLEANING UP WITH ATOM ECONOMY

By Kathryn E. Parent, k_parent@acs.org

Introduction

Cleaning up the environment and, more importantly, preventing pollution are important issues in today's world. The theme for the 2002 National Chemistry Week is "Chemistry Keeps Us Clean." While the chemical industry is traditionally viewed more as a cause than a solution to pollution, chemistry does offer unique solutions in the area of waste prevention. One of the most fundamental of these solutions is the application of the green chemistry principle of atom economy to chemical reactions.

Atom economy moves the practice of minimizing waste to the molecular level. Traditionally, chemists have focused on maximizing yield, minimizing the number of steps or synthesizing a completely unique chemical. Green chemistry and atom economy introduce a new goal into reaction chemistry: designing reactions so that the atoms present in the starting materials end up in the product rather than in the wastestream. This concept provides a framework for evaluating different chemistries, and an ideal to strive for in new reaction chemistry (1,2,3).

Green Chemistry Principle: Atom Economy

Atom economy means maximizing the incorporation of material from the starting materials or reagents into the final product. It is essentially pollution prevention at the molecular level. For example, a chemist practicing atom economy would choose to synthesize a needed product by putting together basic building blocks, rather than by breaking down a much larger starting material and discarding most of it as waste.

Atom economy is an important development beyond the traditionally taught concept of percent yield. Barry Trost, from Stanford University, published the concept of atom economy in *Science* in 1991 (4). In 1998 he received the Presidential Green Chemistry Challenge Award (5) for his work. At the award ceremony, Paul Anderson (1997 ACS President) commented, "By introducing the concept of 'atom economy,' Dr. Trost has begun to change the way in which chemists measure the efficiency of the reactions they design." Atom economy answers the basic question, "How much of what you put into your pot ends up in your product?" (6). To meet the challenge of atom economy, Trost has developed a number of palladium and ruthenium catalysts. These catalysts enable chemical synthesis to proceed by simple addition reactions (7).

Associated Chemistry Topics

- law of conservation of matter
- chemical reactions
- stoichiometry
- percent yield

Vocabulary

Atom Economy –

1) The mass of desired product divided by the total mass of all reagents, times 100

Mass of Desired Product

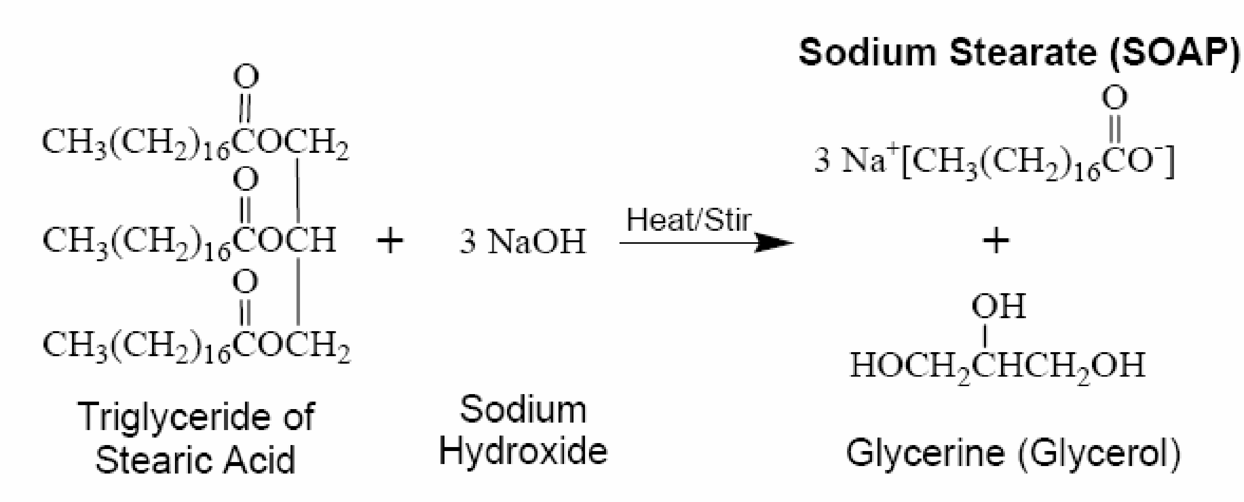
Total Mass of all Reagents

Percent Atom Economy = x 100

2) The mass of desired product divided by the total mass of all products and

byproducts produced, times 100
3) A measure of the efficiency of a reaction (8)
Green Chemistry –
1) Designing chemical products and processes to reduce or eliminate the use or generation of hazardous materials
2) Using chemistry for pollution prevention
3) Benign by design, sustainable chemistry
Molecular Weight – mass of one mole of a compound (units of grams per mole)
Percent Yield – actual yield divided by theoretical yield times 100
Theoretical Yield – the maximum amount of product that can be produced from the quantities of reactants used; the amount of a given product formed when the limiting reactant is completely consumed
Saponification – the decomposition of triglycerides with aqueous sodium hydroxide
Stoichiometry – application of the laws of definite proportions and conservation of mass to chemical processes; quantitative relationship between compounds involved in a reaction

Reaction: Saponification



Background

Saponification, or soap making, is a very old tradition, dating back to 2800 B.C. However, the chemistry was not described until the 19th century by the French chemist, Chevereul. Early soap makers used animal fat and wood ash (which contains sodium hydroxide and potassium carbonate). Now a wide variety of materials and methods are available to the soap maker. Today, soap making is not only highly visible in the mainstream manufacturing industry (names like Ivory, Dove, Dial), but many specialty product industries center around handmade soaps as well.
An excellent resource including the history, chemistry and manufacture of soaps and detergents is available from the Soaps and Detergents Association Web Site:
http://www.sdahq.org/cleaning/
Related information including stories about soap and detergent companies can be found at:
http://inventors.about.com/library/inventors/blsoap.htm
A brief discussion, with excellent graphical models, of the chemistry of soap making can

be found at:
http://antoine.frostburg.edu/chem/senese/101/consumer/faq/making-soap.shtml
Clear directions, including pictures, for making soap are available at the Web Site:
http://www.soapcrafters.com/makebase.htm

Materials (per group of students)

1. Molecular models – many different kits are available or they can be generated from colored Styrofoam balls and toothpicks.
You will need:
a. 6 medium-sized black balls for carbon atoms
b. 9 medium-sized red balls for oxygen atoms
c. 8 small white balls for hydrogen atoms
d. 3 small blue balls for sodium atoms
e. 3 large oblong pieces to represent the hydrocarbon tail of the triglyceride
f. 28 toothpicks for the bonds between the atoms
2. Periodic Table
3. Calculator or computer spreadsheet program like Microsoft Excel

Procedure

I. Build molecular models of the starting materials.
You can use a representative piece, rather than 18 individual carbon atoms and 35 individual hydrogen atoms, for the long hydrocarbon tail of the triglyceride.
II. Identify the desired product, soap, and the waste byproducts that are generated by the reaction. Convert the starting materials into the products. Use the models to help you visualize the transfer of atoms from starting material to product.
III. Generate a table for the saponification reaction summarizing the following information: (Use of a spreadsheet program to generate the tables and do the calculations is recommended.)
A. List the name and stoichiometric coefficient of each starting material (reagent)
B. For each reagent –
1. List the atomic symbol, atomic mass and quantity (remember to include stoichiometric coefficients) of each type of atom in the reagent.
2. Calculate the sum of the masses of all the atoms in the reagent. If the stoichiometric coefficient is 1, the sum of the masses is the molecular weight of the reagent.
Mass = Quantity of Atoms x Atomic Mass of Atoms
C. Add the masses of the reagents (step B2) to find the total mass of all reagents.
D. For each reagent –
1. Identify the atomic symbol, atomic mass and quantity (remember to include stoichiometric coefficients) of the atoms that are utilized in the product.
2. Calculate the sum of the masses of the atoms utilized in the product.
3. Identify the atomic symbol, atomic mass and quantity (remember to include stoichiometric coefficients) of the atoms that are utilized in the byproduct.
4. Calculate the sum of the masses of the atoms utilized in the byproduct.
E. Add the masses of the atoms from each reagent that are utilized in the product (step D2) to find the total mass of all atoms utilized in the product.
This is the theoretical yield of soap from one mole of the triglyceride reagent.
If only one mole of product were produced, the total mass of all the atoms

would also be the molecular weight of the product. However, three moles of soap are produced, so the molecular weight (the mass of one molecule) of the soap is 1/3 of the total of all the atoms in the product.
F. Add the masses of the atoms from each reagent that are utilized in the byproduct to calculate the total mass of all the atoms wasted.
G. Calculate the atom economy for the saponification reaction by dividing the total mass of atoms utilized in the product (step E) by the total mass of all the reagents (step C) and multiplying by 100. Since all the products produced are known, you could instead divide by the total mass of products and byproducts.

Questions

1. What is the atom economy for the saponification reaction, assuming 100% yield (3 soap molecules for every triglyceride used)?
2. What is the atom economy if only two soap molecules were made (66% yield) for every triglyceride molecule reacted (include the third soap molecule in the waste instead of the product).
3. What is the theoretical yield (in grams) of soap if 500.0 grams of the triglyceride of stearic acid are used?
4. What are some basic characteristics of reactions that have high atom economy?
5. Do you think it is more important to have high percent yield or high atom economy? Why?
6. BONUS: Describe modifications you would make to the saponification reaction to increase the atom economy.

Student Worksheet **Name**________________________

Stoichiometric Coefficient, Name of Starting Material	Atomic Symbol, Quantity, Atomic Mass of each atom	Mass (Quantity Times Atomic Mass) of all atoms	Atoms Utilized in Product	Mass of Atoms Utilized in Product	Atoms Wasted in Byproducts	Mass of Atoms Wasted in Byproducts

Calculated Atom Economy: ________________

Instructional Notes

Estimated Time of Activity: 1-2 Hours

Materials (per group of students)

1. Molecular models – many different kits are available or they can be generated from colored Styrofoam balls and toothpicks. You will need:
   a. 6 medium-sized black balls for carbon atoms
   b. 9 medium-sized red balls for oxygen atoms
   c. 8 small white balls for hydrogen atoms
   d. 3 small blue balls for sodium atoms
   e. 3 large oblong pieces to represent the hydrocarbon tail of the triglyceride
   f. 28 toothpicks for the bonds between the atoms
2. Periodic Table
3. Calculator or computer spreadsheet program like Microsoft Excel

Grade Level: High School, Undergraduate

Considerations and Adaptions

Considerations: This activity was written for high school or undergraduate chemistry students. Be sure the students understand how to calculate molecular weights and use

stoichiometric relationships. The calculations are a little tricky since there are three moles of sodium hydroxide and soap per one mole of triglyceride. You may wish to minimize the time involved by providing the molecular formulas and weights [$C_{57}H_{110}O_6$, 891.45 g/mol; NaOH, 40.00 g/mol; $NaC_{18}H_{35}O_2$, 306.45 g/mol]. Use of a spreadsheet is recommended to generate the tables and calculate molecular weights and atom economy. If you wish to introduce the mechanism of the saponification reaction
(nucelophilic attack of the hydroxide ions on the carbonyl), you can emphasize that the oxygen from the NaOH is found in the soap product and the oxygen in the glycerine come from the triglyceride. Students will most likely assume the hydroxide ions become the alcohols in glycerine if not told otherwise. The source of the oxygen atoms will not affect the calculation of atom economy. As an extension, you might consider having the students perform the saponification reaction to make their own soap.

Less Advanced: The activity could be adapted for middle school (and possibly late elementary) students by using Legos instead of molecular models (9). Converting Lego trucks to tractors or vice versa provides a more concrete picture of the process of a chemical reaction. Fruit or chewy-candy could be used as an alternative to Styrofoam balls or molecular models.

More Advanced: The atom economy activity is also a relevant prelab exercise for more advanced chemistry students. By providing less detailed procedural information and a more challenging reaction, the process can be easily adapted for more experienced students. For an organic course, the atom economy could be calculated for all of the basic reaction types. Selectivity, percent conversion, productivity, rates, catalysis and electrochemistry are all chemistry topics that would enhance this discussion of atom economy. A detailed study of the mechanisms of Trost's catalysts (10) would be a challenging topic for advanced inorganic chemistry courses.

Sample Table

The following table shows the calculation of atom economy (54.98%) for the combustion of methane.

$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$$

Stoichiometric Coefficient, Name of Starting Material	Atomic Symbol, Quantity, Atomic Mass of each atom	Mass (Quantity Times Atomic Mass) of all atoms	Atoms Utilized in Product	Mass of Atoms Utilized in Product	Atoms Wasted in Byproducts	Mass of Atoms Wasted in Byproducts
1 Methane	1C, 12.01, 4H, 1.008	16.04	1C	12.01	4H	4.03
2 Oxygen	4O, 16.00	64.00	2O	32.00	2O	32.00
Totals:		80.04	1C, 2O	44.01	4H, 2O	36.03
Product: 1 Carbon Dioxide	1C, 2O	44.01			Atom Economy:	54.98%

The sample calculations are based on the arbitrary designation of carbon dioxide as the product, and water as the byproduct. Alternatively, water could be the desired product and carbon dioxide (a greenhouse gas) could be considered the waste, giving an atom economy of 85.00%. However, the only truly desired product of combustion is the heat or the work of the expanding gases. If both chemical products are designated as waste, the atom economy is 0%.

Answers to Questions

Use of a spreadsheet to generate the tables and calculate formula weights and atom economy is recommended. A blank Student Worksheet is provided on page 6.

1. **90.89%**, see following table:

Stoichiometric Coefficient, Name of Starting Material	Atomic Symbol, Quantity, Atomic Mass of each atom	Mass (Quantity Times Atomic Mass) of all atoms	Atoms Utilized in Product	Mass of Atoms Utilized in Product	Atoms Wasted in Byproducts	Mass of Atoms Wasted in Byproducts
1 Triglyceride of Stearic Acid	57C, 12.01; 110H, 1.008; 6O, 16.00	891.45	54C, 105H, 3O	802.38	3C, 5H, 3O	89.07
3 Sodium Hydroxide	3H, 1.008; 3O, 16.00; 3Na, 22.99	119.99	3Na, 3O	116.97	3H	3.02
Totals:	57C, 113H, 3Na, 9O,	1011.44	54C, 105H, 3Na, 6O	919.35	3C, 8H, 5O	92.09
Product: 3 Sodium Stearate	54C, 105H, 3Na, 6O	919.35			Atom Economy:	90.89%

2. **60.60%**, see following table:

Stoichiometric Coefficient, Name of Starting Material	Atomic Symbol, Quantity, Atomic Mass of each atom	Mass (Quantity Times Atomic Mass) of all atoms	Atoms Utilized in Product	Mass of Atoms Utilized in Product	Atoms Wasted in Byproducts	Mass of Atoms Wasted in Byproducts
1 Triglyceride of Stearic Acid	57C, 12.01; 110H, 1.008; 6O, 16.00	891.45	36C, 70H, 2O	534.92	21C, 40H, 4O	356.53
3 Sodium Hydroxide	3H, 1.008; 3O, 16.00; 3Na, 22.99	119.99	2Na, 2O	77.98	3H, 1Na, 1O	42.01
Totals:	57C, 113H, 3Na, 9O,	1011.44	36C, 70H, 2Na, 4O	612.90	21C, 43H, 1Na, 5O	398.54
Product: 2 Sodium Stearate	36C, 70H, 2Na, 4O	612.90			Atom Economy:	60.60%

3. 500.0 g SM / 891.45 g/mol SM = 0.5602 mol SM
0.5602 mol SM * 3 mol soap/1 mol SM = 1.681 mol soap
1.681 mol soap * 919.35 g soap/3 mol soap = **515.1 g soap**

4. High atom economy characteristically involves rearrangement or addition (e.g. Diels-Alder, Claisen) rather than substitution or elimination processes (e.g. Wittig, Grignard), and makes use of catalytic rather than stoichoimetric reagents. Atom

economical reactions incorporate as much of the starting materials as possible into the product, so solvent-free systems are another characteristic feature.
5. Open ended question. Possibilities include:
High atom economy might be preferred over high yield because it is more efficient and less waste is produced.
High percent yield might be preferred over high atom economy because more of the product is produced.
High yield with low atom economy might be preferred if a recyclable byproduct is formed.
6. BONUS: Suggested answers, any logical reasoning is acceptable.
Using a lower molecular weight base and/or a higher molecular weight triglyceride would reduce the mass of waste and/or increase the mass of the product, thus increasing the atom economy. Considering glycerol (glycerine) a product, rather than a byproduct would remove it from the waste accounting. Making soap directly from the fatty acid rather than the triglyceride would reduce the waste for this reaction, but where does the fatty acid come from?).

References:

(1) Anastas, P. T,; Warner, J. C. *Green Chemistry: Theory and Practice*, Oxford University Press: Oxford, UK, 1998.
(2) Cann, M. C.; Connelly, M. E. *Real World Cases in Green Chemistry*, American Chemical Society: Washington, DC, 2000. See also the University of Scranton's Greening Across the Curriculum Web Site, http://academic.scranton.edu/faculty/CANNM1/organicmodule.html
(3) Ryan, M. A.; Tinnesand, M., Eds. *Introduction to Green Chemistry*, Washington, DC: American Chemical Society, 2002.
(4) Trost, B. M. *Science* **1991,** *254,* 1471-1477.
(5) The Presidential Green Chemistry Challenge is an award program sponsored jointly by the Environmental Protection Agency (Office of Pollution Prevention and Toxics) and the American Chemical Society—Green Chemistry Institute. Introduced in 1995, it is the only program to provide national recognition for green chemistry. The program offers five awards to academic researchers, industry, and government laboratories for innovations in the following categories: 1) academic, 2) small business, 3) alternative reaction conditions, 4) alternative synthesis, and 5) design of safer chemicals. For information about the Presidential Green Chemistry Challenge, refer to the Web Site: http://www.epa.gov/greenchemistry/presgcc.html
(6) Trost, B. M. In *The Presidential Green Chemistry Challenge Awards Program: Summary of the 1998 Award Entries and Recipients*; EPA744-R-98-001, U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics: Washington, DC, 1998; p 2.
(7) Trost, B. M. *Acc. Chem. Res.* **2002,** *35,* 695-705.
(8) For a powerpoint presentation of atom efficiency, with excellent examples, see the Green Chemistry Network Web Site, http://www.chemsoc.org/pdf/gcn/atomeff.ppt
(9) Witzel, J. Eric. *J. Chem. Educ.* **2002,** *79*, 352A-352B.
(10) Trost, B. M. *Acc. Chem. Res.* **2002,** *35,* 695-705.

APPENDIX 19: GREEN CHEMISTRY REACTIONS FOR UNDERGRADUATE STUDENTS

Further information about each of these reactions can be found on the GEMs (Greener Educational Materials for Chemists) through the University of Oregon's chemistry department's website.

Appendix 19.1

Patterning Self-Assembled Monolayers on Gold. Green Materials Chemistry in the Teaching Laboratory

Author Contact: **hutch@uoregon.edu**

Summary

Applications of organic chemistry to modify structure and surface properties of materials are becoming increasingly important and interdisciplinary as the dimensions of modern materials decrease. This laboratory exercise illustrates how macroscopic material properties can be modified with self-assembled monolayers and organic thin-film patterning. Using an inexpensive gold on vinyl substrate, students investigate the wettability of surfaces prepared using functionalized alkanethiol monolayers with either hydrophobic or hydrophilic terminating groups. The functionalized alkanethiols are used with microcontact printing techniques to pattern a surface that can be visualized in the presence of water vapor. The self-assembly of alkanethiol monolayers is ideally suited to introduce waste reduction, dematerialization, and improved energy efficiency as green chemistry principles. In addition, self-assembly produces less solvent waste compared to spin coating techniques commonly used to prepare surface films.

Supplemental materials are provided on the J. Chem. Educ. website and include detailed introductory and background information, instructions for students and notes for the instructors.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

McKenzie, L. C.; Huffman, L. M.; Parent, K. E.; Hutchison, J. E.; Thompson, J. E. *J. Chem. Educ.* **2004**, *81*, pp 545-548.

J. Chem. Educ. (Abstract only)

Appendix 19.2

Preparation and Distillation of Cyclohexene

Laboratory Procedures (PDF)

Author Contact: **hutch@uoregon.edu**

Summary

The preparation of cyclohexene by acid catalyzed dehydration is a classic in the cannon of undergraduate laboratory instruction; this reaction is an example of a greener variation of the reaction.
In this exercise the focus is on the use of concentrated (85%) H_3PO_4 in place of the stronger - and more corrosive - H_2SO_4 as the catalyst. Students' attention is drawn to the fact that when a liquid alcohol is dehydrated there is no need for additional 'solvent', only the alcohol and catalytic quantities of strong acid are required. Consistent with the emphasis "green chemistry" puts on the atom economy (atom efficiency) of a reaction, this exercise illustrates that the formation of water that occurs not only reduces atom economy but also represents a 'by-product' (waste) that must be dealt with appropriately (freed of acid, and purified for reuse). Nonetheless, water is certainly the most benign of by-products. Similarly, the use of a drying agent represents another relatively benign disposal matter.

The link to the laboratory procedure includes pre- and post- lab questions.

Summary prepared July 2005 by Rita Hessley, Department of Chemical Technology at the University of Cincinnati.

Source

Doxsee, K. M.; Hutchison, J. E. *Green Organic Chemistry - Strategies, Tools, and Laboratory Experiments* 2004; pp 129-134.

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Category Descriptors

Appendix 19.3

Palladium-Catalyzed Alkyne Coupling/Intramolecular Alkyne Addition: Synthesis of a Benzofuran Product

Laboratory Procedures (PDF)

Author Contact: **hutch@uoregon.edu**

Summary

This laboratory module focuses on aqueous organometallic chemistry where a terminal alkyne (2-methyl-3-butyne-2-ol) is coupled with 4-hydroxy-3-iodo-acetophenone in a reaction catalyzed by a palladium complex resulting in the synthesis of a benzofuran product. Traditional palladium-catalyzed alkyne coupling addition methods, involving deprotonated alkynes, are carried out in organic solvent with the careful exclusion of water. The use of metal-catalyzed reactions in water considerably reduces the hazards and environmental impact associated with traditional reactions because the catalyzed reactions can be conducted under mild conditions and they eliminate or reduce the use and disposal of organic solvents.

This greener synthesis is usually carried out over the course of two lab periods. During the first session, students measure out reagents and set up the reaction and during the second session, students isolate, purify, and characterize the product. The link to the laboratory procedures includes pre- and -post lab questions.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Gilbertson, R.; Doxsee, K.; Succaw, G.; Huffman, L.; Hutchison, J. E. Palladium-Catalyzed Alkyne Coupling/Intramolecular Alkyne Addition: Synthesis of a Benzofuran Product *Greener Approaches to Undergraduate Chemistry Experiments* Kirchhoff, M.; Ryan, M., Eds.; American Chemical Society: Washington D.C., 2002; pp 4-7.

Category Descriptors

Appendix 19.4

Solvent-Free Synthesis of Chalcones

Author Contact: **palleros@chemistry.ucsc.edu**

Summary

Chalcones represent a group of compounds with interesting biological activities that are formed from an aldol condensation between a benzaldehyde and an acetophenone in the presence of NaOH as a catalyst. Although typically synthesized using organic solvents, in this exercise students prepare 20 different chalcones using a solventless procedure. The scale of these reactions can be easily modified due to the high yields and ease of purifications. A diverse set of reactants combined with differential product profiles for traditional vs. solventless reactions, provides a unique framework for discussing how a broad range of chemical and physical properties affect product yields.

Supplemental materials are provided on the J. Chem. Educ. website and include notes for instructors and students, an experimental procedure, hazards, sample results and conclusions.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Palleros, D. R. *J. Chem. Educ.* **2004**, *81*, pp 1345-1347.

J. Chem. Educ. (Abstract only)

Appendix 19.5

Oxidative Coupling of Alkynes: The Glaser-Eglinton-Hay Coupling

Laboratory Procedures (PDF)

Author Contact: **doxsee@uoregon.edu**

Summary

The Glaser-Eglinton-Hay reaction has been used to synthesize a number of fungal antibiotics and is important for carbon-carbon bond formation via the oxidative coupling of alkynes. This laboratory exercise illustrates the oxidative coupling of 1-ethynylcyclohexanol in the presence of cuprous chloride, tetramethylethylenediamine and air. Typically, pyridine has been used as a solvent in this type of reaction, but a greener solvent, 2-propanol, is used in this procedure.

A complex mechanism has been proposed for this copper catalyzed coupling reaction. The acetylide, formed by deprotonation of the terminal alkyne, reacts with the cuprous chloride to produce a copper (Cu^{+1}) acetylide complex. Air is bubbled through the reaction solution to oxidize Cu^{+1} to Cu^{+2}. The Cu^{+2} is then reduced to Cu^{+1}, resulting in the formation of the alkyne coupling product. The link to the laboratory procedure includes post-lab questions.

Summary prepared July 2005 by Christine K. F. Hermann, Department of Chemistry and Physics at Radford University.

Source

Doxsee, K. M.; Hutchison, J. E. *Green Organic Chemistry - Strategies, Tools, and Laboratory Experiments* 2004; pp 142-151.

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Appendix 19.6

One-Pot Synthesis of 7-Hydroxy-3-carboxycoumarin in Water

Author Contact: **frifra@unipg.it**

Summary

Coumarins represent an important class of natural and synthetic derivatives with interesting biological activities. The 3-carboxycoumarins have been intensely studied because new functionalities can be easily added via the carboxyl group. During this laboratory exercise, students prepare 7-hydroxy-3-carboxycoumarin using a one-pot, multi-step procedure in the absence of organic solvents. By using water as a solvent, students investigate the advantages of being able to perform multiple synthetic steps in sequence by simply changing the pH. The ability to isolate desired products by filtration minimizes the use of additional solvents.

The laboratory exercise is appropriate for an undergraduate organic chemistry laboratory course and is designed to accommodate suitable stopping points for two or three lab periods. The multi-step reaction pathway can be monitored by TLC and consists of four fundamental steps starting with a Knoevenagel condensation and Pinner reaction followed by acid catalyzed hydrolysis of iminocyanide. After basic hydrolysis of the cyanolactone and subsequent acidification, the reaction mixture yielded 98% pure 7-hydroxy-3carboxycoumarin with an overall yield of 85%. Supplemental materials include detailed experimental procedures, notes for the instructor and interpretation of the TLC plates. IR and ^{1}H and ^{13}C NMR spectra are also available.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Fringuelli, F.; Piermatti, O.; Pizzo, F. *J. Chem. Educ.* **2004**, *81*, pp 874-876.

J. Chem. Educ. (Abstract only)

Appendix 19.7

Microwave Synthesis of Tetraphenylporphyrin

Laboratory Procedures (PDF)

Author Contact: **hutch@uoregon.edu**

Summary

In the present experiment students prepare a porphyrin, tetraphenylporphyrin, from four molecules each of pyrrole and benzaldehyde. The carbon framework of the porphyrin is assembled through eight electrophilic substitutions between benzaldehyde and pyrrole to produce a porphyrinogen. Oxidation of the porphyrinogen during the reaction yields the porphyrin (an 18-electron aromatic compound).

Traditionally, porphyrin syntheses have been carried out in corrosive, high-boiling solvents, such as propionic acid or have been done in large volumes of a halogenated solvent containing a corrosive Lewis acid catalyst. In many cases, toxic oxidizing compounds are used to convert the porphyrinogen to porphyrin. In this experiment, students employ a method of porphyrin synthesis that is solventless-it is carried out on a solid support. The two reagents, pyrrole and benzaldehyde, react on the support under irradiation in a conventional microwave oven. The product is eluted off the solid support with a small amount of solvent. Usually one purifies porphyrins by column chromatography often employing chlorinated solvents such as methylene chloride or chloroform. In this experiment, a safer chromatography solvent mixture (hexanes and ethyl acetate) is used. The link to the laboratory procedures includes pre- and -post lab questions.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Warner, M.; Succaw, G.; Doxsee, K.; Hutchison, J. E. Microwave Synthesis of Tetraphenylporphyrin *Greener Approaches to Undergraduate Chemistry Experiments* Kirchhoff, M.; Ryan, M., Eds.; American Chemical Society: Washington D.C., 2002; pp 27-31.

Appendix 19.8

Micelle-Mediated Extraction of Heavy Metals from Environmental Samples: An Environmental Green Chemistry Laboratory Experiment

Author Contact: **mkaragia@cc.uoi.gr**

Summary

Analysis of trace metals and organic substances often rely on the use of organic solvent-based extractions. In this laboratory exercise, students will use analytical chemistry to determine heavy metals from water samples using a greener, micelle-mediated extraction procedure called a cloud-point extraction. Water samples are treated with a chelating agent, ammonium pyrrolidinedithiocarbamate, and the nonionic surfactant Triton X-114. After acidifying the solution, samples are heated to promote micelle formation and heavy metals are removed with the surfactant-rich phase. Samples are heated to remove remaining water and then prepared for atomic absorption spectroscopy operating in the flame mode. Developed for an undergraduate analytical chemistry laboratory this exercise focuses on the fundamental concepts of micelle formation, phase separation and cloud-point extraction methodology. The greener, micelle mediated preconcentration technique replaces high volume, more hazardous organic solvent extraction methods.

Supplemental materials are provided on the J. Chem. Educ. website and include instructor notes.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Giokas, D. L.; Paleologos, E. K.; Karayannis, M. I. *J. Chem. Educ.* **2003**, *80*, pp 61-64.

J. Chem. Educ. (Abstract only)

Appendix 19.9

Metallation of Tetraphenylporphyrin

Laboratory Procedures (PDF)

Author Contact: **hutch@uoregon.edu**

Summary

Coordination complexes are important throughout chemistry and biology. They act as catalysts, drugs, oxygen carriers, and electron transfer agents. In this experiment, students metallate tetraphenylporphyrin with zinc using zinc acetate. Students monitor the metallation by observing the changes in the absorption spectrum by using visible spectroscopy. Students observe the Zn^{2+} that was colorless in solution, forming a blood red complex with the tetraphenylporphyrin ligand. In addition, the porphyrin changes the solubility of the zinc ion. Thus, ligands such as the porphyrin can be used to impart new properties (optical or solubility) to a metal through the formation of a complex.

Reaction of the metal-free porphyrin ligand with the metal salt inserts the metal into the four-fold (tetradentate) binding site (metallation). Typically, halogenated solvents or dimethylformamide are used to metallate porphyrins. In this experiment, students use two, more benign solvents, 1-methyl-2-pyrrolidinone (also called N-methylpyrrolidinone) and dimethylsulfoxide to dissolve both of the reagents and ensure facile reaction.

The solvents used in this metallation offer less health and environmental hazards than the traditionally used solvents such as chlorinated hydrocarbons and N,N-dimethylformamide. Further the reaction is conducted at room temperature instead of the elevated temperatures traditionally used. The link to the laboratory procedures includes pre- and -post lab questions.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Warner, M.; Hutchison, J. E. *Greener Approaches to Undergraduate Chemistry Experiments* Kirchhoff, M.; Ryan, M., Eds.; American Chemical Society: Washington D.C., 2002; pp 32-34.

Appendix 19.10

Greener Approaches to Undergraduate Chemistry Experiments

Author Contact: **education@acs.org**

Summary

This laboratory manual contains 14 green chemistry experiments suitable for the undergraduate level. Most of the experiments are green analogs of typical undergraduate organic chemistry experiments that highlight traditional chemical concepts with more environmentally friendly reactions and methods. A few of the experiments could be used for inorganic, materials science, general and non-major chemistry laboratories. Each experiment includes an introduction, prelab questions, chemicals and equipment needed experimental procedure, safety precautions, cleanup, and postlab questions. The relevant principles of green chemistry are discussed for each experiment and students are asked to assess the green-ness of the experiment and explore opportunities for improvement. Most of the experiments have been published in other textbooks or journals. This collection is a useful supplement for undergraduate faculty interested in incorporating green chemistry into the curriculum.

Summary prepared July 2005 by Joe Workman, Department of Chemistry at Centre College and Kathryn Parent at the American Chemical Society Green Chemistry Institute.

Source

Greener Approaches to Undergraduate Chemistry Experiments Kirchhoff, M.; Ryan, M., Eds.; 2002;

How to order this publication

Appendix 19.11

Gas-Phase Synthesis, Column Chromatography and Visible Spectroscopy of 5,10,15,20-Tetraphenylporphyrin

Summary

DATA ENTRY IN PROGRESS

This experiment involves the synthesis and characterization of a simple porphyrin: 5,10,15,20-tetraphenylporphyrin. This product is a structural analog of important biomolecules, such as the heme portion of the oxygen-transport molecule hemoglobin and chlorophyll of plants.

The carbon skeleton of the porphyrin ring is prepared by eight electrophilic aromatic substitution reactions between four equivalents of pyrrole and benzaldehyde. Traditionally, porphyrin syntheses have been carried out in corrosive, high-boiling solvents. Toxic reagents have been used to oxidize the intermediate porphyrinogen ring to porphyrin.

In this experiment, porphyrinogen is prepared by the solvent-less reaction between pyrrole and benzaldehyde in the gas phase, and then oxidized to porphyrin by air oxygen. The product is identified by thin-layer chromatography, purified by column chromatography, and further characterized by ultraviolet-visible spectroscopy.

This gas-phase reaction eliminates the need for hazardous solvents, avoids the use of corrosive reagents, and uses air as a mild and safe oxidant for converting porphyrinogen to porphyrin. The link to the laboratory procedure includes pre- and post-lab questions.

Summary prepared July 2005 by Don T. Fujito, Chemistry Department, La Roche College.

Source

Doxsee, K. M.; Hutchison, J. E. *Green Organic Chemistry - Strategies, Tools, and Laboratory Experiments* 2004; pp 152-158.

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Category Descriptors

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Appendix 19.12

Electrophilic Aromatic Iodination of 4'-Hydroxyacetophenone

Laboratory Procedures (PDF)

Author Contact: **hutch@uoregon.edu**

Summary

Aromatic halogenation is an important tool for the conversion of aromatic compounds into specific compounds of interest or importance. This laboratory module investigates the iodination of 4'-hydroxyacetophenone using sodium iodine and household bleach (as an oxidizing agent) in aqueous ethanol. The reaction conditions used in this laboratory module offer two advantages over more traditional methods: (1) the reaction is efficient and selective leading to good yields of monoiodinated product and (2) the method offers more environmentally benign reaction conditions (less hazardous oxidizing agent - NaOCl vs. nitric acid and a relative benign solvent- ethanol). The link to the laboratory procedures includes pre- and -post lab questions.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Gilbertson, R.; Parent, K.; McKenzie, L.; Hutchison, J. E. Electrophilic Aromatic Iodination of 4'-Hydroxyacetophenone *Greener Approaches to Undergraduate Chemistry Experiments* Kirchhoff, M.; Ryan, M., Eds.; American Chemical Society: Washington D.

Appendix 19.13

Chiral Compounds and Green Chemistry in Undergraduate Organic Laboratories: Reduction of a Ketone by Sodium Borohydride and Baker's Yeast

Author Contact: **npohl@iastate.edu**

Summary

Chiral compounds can have unique properties and are becoming increasingly important in pharmaceutical, chemical and agricultural industries. In this laboratory exercise, students compare and contrast chemical vs. enzyme-mediated procedures for introducing chirality into a molecule and gain experience with the principles and experimental techniques used to prepare and separate enantiomers. Over the course of four, 3-hour lab periods, students characterize (1) racemic and enantiomerically enriched products of the sodium borohydride reduction of ethyl acetoacetate with and without the use of a L-tartaric acid and (2) products obtained with an enzyme-mediated reduction using Baker's yeast. This exercise provides a framework for discussing some of the unique challenges associated with using enzyme-mediated procedures for developing environmentally benign chiral syntheses.

Supplemental materials are provided on the J. Chem. Educ. website and include instructor notes and student handouts for the laboratory procedure and the chiral GC analysis.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Pohl, N.; Clague, A.; Schwarz, K. *J. Chem. Educ.* **2002**, *79*, pp 727-728.

J. Chem. Educ. (Abstract only)

Appendix 19.14

Carbonyl Chemistry: Thiamine-Mediated Benzoin Condensation of Furfural

Laboratory Procedures (PDF)

Author Contact: **doxsee@uoregon.edu**

Summary

This experiment is a greener version of the classical benzoin condensation reaction, where students are shown a method for making C-C bonds and learn carbonyl chemistry. In this version, benzaldehyde is replaced by furfural and toxic sodium cyanide is replaced by sodium hydroxide and catalytic amounts of thiamine hydrochloride (vitamin B1). The use of thiamine hydrochloride represents one of the earliest examples of biologically derived reagents being used as a catalyst.

The reaction can be generally applied to other aryl aldehydes. Furfural (furan-2-carboxy aldehyde) is used in place of benzaldehyde to illustrate that heterocyclic aromatic compounds undergo condensations analogous to their benzene counterparts. Students will observe the formation of a light tan crystalline crude product. The crude product is vacuum filtered and recrystallized in ethanol to obtain a pure white material which is analyzed by infrared spectroscopy. Students are asked to interpret the IR spectrum of the product, determine its melting point, calculate the atom economy, and perform an economic evaluation of the process. The resulting product, furoin, can be easily oxidized under mild oxidation conditions to give furil (an alpha-diketone). The link to the laboratory procedure includes pre- and post-lab questions.

Summary prepared July 2005 by Joshua Pak, Department of Chemistry at Idaho State University and Scott W. Cowley, Department of Chemistry and Geochemistry at the Colorado School of Mines.

Source

Doxsee, K. M.; Hutchison, J. E. *Green Organic Chemistry - Strategies, Tools, and Laboratory Experiments* 2004; pp 201-205.

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Appendix 19.15

Green Chemistry in the Organic Teaching Laboratory: An Environmentally Benign Synthesis of Adipic Acid

Author Contact: **hutch@uoregon.edu**

Summary

Industrial production of adipic acid involves the oxidation of cyclohexanol, cyclohexanone, or both by nitric acid. An inevitable byproduct of this reaction is nitrous oxide, implicated in the process of global warming and ozone depletion. In this experiment, students synthesize adipic acid using sodium tungstate-catalyzed oxidation of cyclohexene by hydrogen peroxide in water.

This method replaces a hazardous oxidizing agent with an environmentally benign one, uses water as the solvent, and teaches the benefits of using a recyclable catalyst. The experiment introduces important laboratory techniques including recrystallization and phase-transfer catalysis while providing an opportunity to introduce polymer chemistry.

Supplemental materials are provided on the J. Chem. Educ. website and include laboratory procedures and a student report template.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Reed, S. M.; Hutchison, J. E. *J. Chem. Educ*. **2002**, *77*, pp 1627-1629.

J. Chem. Educ. (Abstract only)

Appendix 19.16

An Asymptotic Approach to the Development of a Green Organic Chemistry Laboratory

Author Contact: **goodwin@hendrix.edu**

Summary

This article provides a rationale and stepwise process for evaluating and improving the "greenness" of an undergraduate organic chemistry laboratory curriculum. After emphasizing the educational value of sharing this process with students, effective risk assessment is discussed as an important tool for both evaluating and redesigning laboratory exercises. The greening process is illustrated by describing modifications of three undergraduate laboratory exercises (palladium-catalyzed coupling reactions, steroselective reduction reactions and alkene epoxidations) through the use of safer solvents and reagents. By asking each student to describe and evaluate the greenness of a given laboratory exercise and to provide recommendations for how the procedure could be made greener, we are helping our students appreciate the important role of environmentally responsible laboratory practices and thought processes in our society.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Goodwin, T. E. *J. Chem. Educ.* **2004**, *81*, pp 1187-1190.

J. Chem. Educ. (Abstract only)

Appendix 19.17

Alkene Isomerization Using a Solid Acid as Activator and Support for a Homogeneous Catalyst

Author Contact: **A.J.Seen@utas.edu.au**

Summary

In this laboratory experiment, students explore the use of an immobilized $Ni[P(OEt)_3]_4$-H_2SO_4 catalyst system to study the isomerization of 1-octene to *trans*- and *cis*- 2-octene. Nafion-H^+ is a solid acid ion exchange polymer that both activates the air-sensitive transition metal catalyst and immobilizes the cationic species that can be characterized by UV-vis spectroscopy within the polymer matrix. The isomerization is performed under nitrogen at room temperature and can be completed in two three- or four-hour lab sessions. The product ratio changes throughout the reaction and can be used to illustrate the equilibrium distribution of kinetic vs. thermodynamically stable products.

Supplemental materials are provided on the J. Chem. Educ. website and include student instructions and procedures for preparation of the catalyst and characterization of the Nafion immobilized species.

Summary prepared May 2005 by Julie A. Haack, Department of Chemistry at the University of Oregon.

Source

Seen, A. J. *J. Chem. Educ.* **2004**, *81*, pp 383-384.

J. Chem. Educ. (Abstract only)

APPENDIX 20: PUBLICITY EXAMPLES

Appendix 20.1: Logos – The green chemistry network we propose will be a chapter of the Green Chemistry Institute in the United States.

1: Brief logo used in letter heads and website

2: More informational logo for use on flyers and brochures

Appendix 20.2. Flyer This flyer can be used as a poster or handout to place around universities chemistry departments.

Chulalongkorn University

Green Chemistry Institute Thailand

GREEN CHEMISTRY WORKSHOP

Date: January 15, 2007

Time: 8:00 to 15:00

Mahamakut Building,
Chulalongkorn University
Bangkok, Thailand

Contact person: 555 555 5555

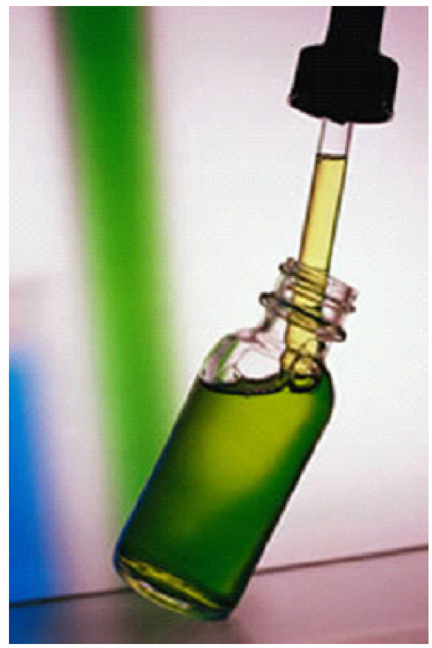
Guest Speakers:

Dr. Supawan Tantayanon— Coordinator of the Thailand Chapter of the Green Chemistry Institute
Professor of Analytical Chemistry, Chulalongkorn University

Dr. John Warner— Co-developer of the 12 principles of green chemistry
Professor of Green Chemistry at the University of Massachusetts Lowell, USA

Dr. Paul Anastas –Director of the Green Chemistry Institute

Green Chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products.



ENVIRONMENTALLY BENIGN CHEMISTRY

Chulalongkorn University

E-mail: Supawan.t@chula.ac.th

Workshop is for Undergraduate Students who have had Organic Chemistry Lab

Register through your chemistry department by December 15, 2006.

Students will perform interactive laboratory experiments in green chemistry to learn how chemistry can help the environment.

Appendix 20.3: Brochure

Green Chemistry

Green chemistry is chemistry that is "*benign by design*." It focuses on changing the initial reactions completed all through the creation of the final product. It is pollution prevention at the molecular level.

Overview of the 12 Principles of Green Chemistry:

1. Prevention
2. Atom Economy
3. Less Hazardous Chemical Syntheses
4. Designing Safer Chemicals
5. Safer Solvents and Auxillaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis
10. Design for Degradation
11. Real-time Analysis for Pollution Prevention
12. Inherently Safer Chemistry for Accident Prevention

City skyline
Bangkok, Thailand

Erawan Falls
Kanchanaburi,
Thailand

EXAMPLE LAB EXPERIMENTS:

- **One-pot synthesis of 7-hydroxy-3-carboxycoumarin in water**

This reaction occurs all in one container! No transferring and losing product. This reaction occurs just by changing the pH of the solution. This reaction is an organic synthesis—but it does not need organic solvents.

- **Solvent-Free Synthesis of Chal-cones**

One way of using green chemistry is to use safer solvents—or to not use them at all. This reaction mixes two solids in order to synthesize a chalcone.

Students should be in undergraduate school and should have taken Organic Chemistry Lab

Registration for Workshop

Sign up for: Time

☐ Green Chemistry Workshop 8:00-15:00

☐ Further Information

Name of University

Name

Address

Phone

Check School Year: ☐ 1st Year ☐ 2nd Year ☐ 3rd Year ☐ 4th Year ☐ Graduate

Chulalongkorn University
Contact person: Dr. Supawan Tantayanon
E-mail: Supawan.t@chula.th.ac

GCI

This brochure provides general information about the workshop and about green chemistry. It also provides a registration form to be mailed in.

Appendix 20.4. Website

This website includes a home page which can describe the network when it is completed and current activities. On the "About Us" page can be located a more in-depth description of the network. The "Green Chemistry Information" page serves as a way to educate others about the importance of green chemistry and why it has evolved. The calendar can show upcoming events and provide links for registration and contact information. The Related links page provides further resources on green chemistry. The projects page can demonstrate a broad overview of research going on within the network with green chemistry.

Home
About Us
Contact Us
Calendar
Project List
Related Links
Green Chemistry Information

Green Chemistry Institute: Thailand Chapter

Making Thailand a safer place

About Us

Mission:

To unify industry, academia, and government in order to achieve a common goal of increasing green chemistry use, education, and policy in Thailand.

City Sky-line
Bangkok, Thailand

History:

Who we are:

A network comprised of researchers from universities (including faculty and graduate students), industry, and government.

To contact us:

E-mail: supawan.t@chula.ac.th

Home | About Us | Contact Us | Calendar | Project List | Related Links | General Information

Green Chemistry Institute: Thailand Chapter

Making Thailand a safer place

Contact Us

- Home
- About Us
- Contact Us
- Calendar
- Project List
- Related Links
- Green Chemistry Information

Director

Dr. Supawan Tantayanon

Professor of Analytical Chemistry

Chulalongkorn University

Tel. #:

Fax #:

Email:

Home | About Us | Contact Us | Calendar | Project List | Related Links | General Information

Home

About Us

Contact Us

Calendar

Project List

Related Links

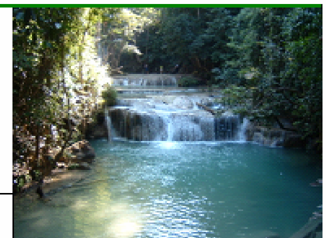
Green Chemistry Information

Green Chemistry Institute: Thailand Chapter

Making Thailand a safer place

Green Chemistry Information

Green Chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products.



Erawan Falls,
Kanchanaburi, Thailand

The 12 Principles of Green Chemistry

It is better to prevent waste than to treat or clean up waste after it is formed.

Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment

Chemical products should be designed to preserve efficacy of function while reducing toxicity.

The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary wherever possible and, innocuous when used.

Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.

A raw material of feedstock should be renewable rather than depleting wherever technically and economically practicable.

Unnecessary derivization (blocking group, protection/ deprotection, temporary modification of physical/ chemical processes) should be avoided whenever possible.

Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation of the products.

Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

Substances and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

From: Anastas and Warner (1998) Figure 4.1, p. 30.

To contact us:

E-mail: supawan.t@chula.ac.th

Home | About Us | Contact Us | Calendar | Project List | Related Links | General Information

Green Chemistry Institute: Thailand Chapter

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Calendar—coming soon!

Home

About Us

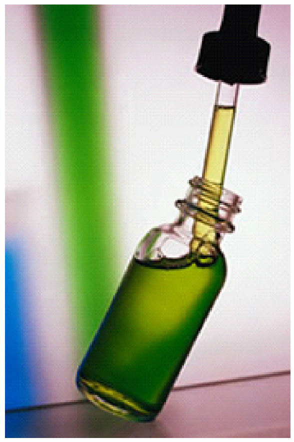
Contact Us

Calendar

Project List

Related Links

Green Chemistry Information



Green Chemistry Workshop

- Tentative February, 2007
- 1 day workshop teaching principles of green chemistry and doing lab experiments

Home | About Us | Contact Us | Calendar | Project List | Related Links | General Information

Home

About Us

Contact Us

Calendar

Project List

Related Links

Green Chemistry Information

Green Chemistry Institute: Thailand Chapter

Making Thailand a safer place

Related Links

Here is some more information on green chemistry and green chemistry clubs and networks:

The Green Chemistry Institute, USA
http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=greenchemistryinstitute%5Cindex.html

The Green Chemistry Network, UK
http://www.chemsoc.org/networks/gcn/

Green and Sustainable Chemistry Network, Japan
http://www.gscn.net/indexE.html

To contact us:

E-mail: supawan.t@chula.ac.th

Home | About Us | Contact Us | Calendar | Project List | Related Links | General Information

Home

About Us

Contact Us

Calendar

Project List

Related Links

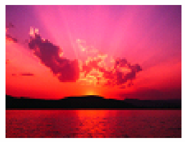
Green Chemistry

Green Chemistry Institute: Thailand Chapter

Making Thailand a safer place

Project List

List your current projects, clients, or activities. To add more projects, copy and paste additional text boxes.



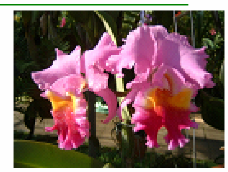
Project name 1

Type a description of the project, client, or activity. Change the picture to one of your own, such as a picture of the project.

- More details…

Project name 2

Type a description of the project, client, or activity. Change the picture to one of your own, such as a picture of the project.



- More details…

Project name 3

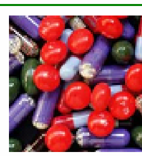
Type a description of the project, client, or activity. Change the picture to one of your own, such as a picture of the project.

- More details…

Project name 4

Type a description of the project, client, or activity. Change the picture to one of your own, such as a picture of the project.

- More details…



Project name 5

Type a description of the project, client, or activity. Change the picture to one of your own, such as a picture of the project.

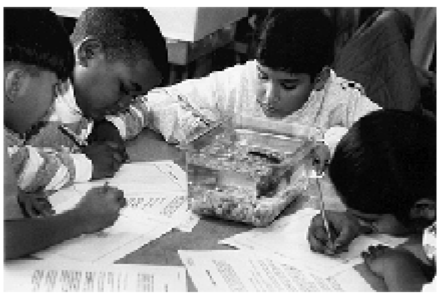
- More details…

Home | About Us | Contact Us | Calendar | Project List | Related Links | General Information

APPENDIX 21: NATIONAL SCIENCE EDUCATION STANDARDS

Science Content Standards

The content standards presented in this chapter outline what students should know, understand, and be able to do in natural science. The content standards are a complete set of outcomes for students; they do not prescribe a curriculum. These standards were designed and developed as one component of the comprehensive vision of science education presented in the *National Science Education Standards* and will be most effective when used in conjunction with all of the standards described in this book. Furthermore, implementation of the content standards cannot be successful if only a subset of the content standards is used (such as implementing only the subject matter standards for physical, life, and earth science). This introduction sets the framework for the content standards by describing the categories of the content standards with a rationale for each category, the form of the standards, the criteria used to select the standards, and some advice for using the science content standards.



Rationale

The eight categories of content standards are

- Unifying concepts and processes in science.
- Science as inquiry.
- Physical science.
- Life science.
- Earth and space science.
- Science and technology.
- Science in personal and social perspectives.
- History and nature of science.

The standard for unifying concepts and processes is presented for grades K-12, because the understanding and abilities associated with major conceptual and procedural schemes need to be developed over an entire education, and the unifying concepts and processes transcend disciplinary boundaries. The next seven categories are clustered for grades K-4, 5-8, and 9-12. Those clusters were selected based on a combination of factors, including cognitive development theory, the classroom experience of teachers, organization of schools, and the frameworks of other disciplinary-based standards. References for additional reading for all the content standards are presented at the end of Chapter 6.

The sequence of the seven grade-level content standards is not arbitrary: Each standard subsumes the knowledge and skills of other standards. Students' understandings and abilities are grounded in the experience of inquiry, and inquiry is the foundation for the development of understandings and abilities of the other content standards. The personal and social aspects of science are emphasized increasingly in the progression from science as inquiry standards to the history and nature of science standards. Students need solid knowledge and understanding in physical, life, and earth and space science if they are to apply science.

Multidisciplinary perspectives also increase from the subject-matter standards to the standard on the history and nature of science, providing many opportunities for integrated approaches to science teaching.