Project/Idea Development:

The original topic/concept we sought out to research was the effects of gamma radiation on plant growth. However, a lot of experimentation had already been done in this field. We then began searching ideas for subject matter from which to base our project. We wanted something current with relatively little prior research. Then, one evening while wasting away on the couch, trying to conjure up project ideas that continue to evade me, a news story came up on the 10 o’clock news about MTBE. This was something in the news, controversial, with little to no prior research. A few days later, we found a newspaper article about MTBE and its increased use in California’s gasoline, this finding further interested us in exploring this field.

We began researching on our project, finding mountains of information on MTBE, without any real focus. It was not until an article that we discovered in “Science News” magazine that caught our attention. Entitled, “Stream-bed Bugs Eat Gasoline Pollutants,” the article showed a study done in South Caroline on local “stream-bed bugs,” bacteria, exposed to toxic run off. Such “bugs” were proven to be effective in decomposing and essentially digesting MTBE. Pursuing research in the degradation of MTBE intrigued us.

We asked our AP Biology teacher, Mr. Thiel for advice on the project. Incidentally, a student from a few years earlier had based her project on MTBE. The abstract of her project was a study of the effects of MTBE on plant growth. However, we saw this to be a very limited topic. Logically, any plant exposed to high enough concentrations of organic chemicals would e negatively affected. We soon contacted our last year’s AP Chemistry teacher, Mrs. Carol de Boer. We had no real idea as to the feasibility nor practicality of seeking a project topic on MTBE. After speaking to her, she said that obtaining MTBE would be difficult to come by. She fortunately, gave us contacts to seek additional help. One of which was Dr. Joy Andrews, Professor of Environmental Chemistry at California State University at Hayward. Mrs. De Boer had spoken to her a year earlier at a conference at Lawrence Livermore National Labs – Dr. Andrews back then had expressed interest in working with students at the high school level.

We came in contact with Dr. Andrews after exchanging a series of e-mails. We soon began consulting with her, proposing our ideas for a project, and receiving advice. She advised us that the project involving the effectiveness on micro-organisms regarding their ability to degrade/digest MTBE would be difficult. The practicality lay in finding and isolating a testable and known bacteria strain as well as maintaining a bacteria culture under the proper conditions; the likes of which would prove to be complicated and very costly.

She soon explained how she and her students conducted research on plants and their abilities to “ remediate ” contaminated water, particularly metallic solids such as mercury and zinc. One such project was studying the effectiveness of water hyacinths in a local river delta. These plants had surprising capabilities to take up and remove heavy metallic solids from the local ecosystem. This process is known as “phytoremeidation,” which is the direct use of living green plants for risk reduction of contaminated soils, sludge’s, sediments, and ground water through contaminant removal, degradation, or containment. Applying this concept towards the possible remediation of contaminated soils with MTBE would be the basis for our project.

As we continued developing our project, we were fortunate enough to begin researching with Christian Thomas, an undergraduate student of chemistry at Cal State Hayward. With Christian as part of our research team, we were able to compose a comprehensive study on the phtyoremediation of MTBE.

Use & Implementation of MTBE:

More than 2.7 billion pounds of air pollutants are emitted annually in the United States, and more 100 million American cities fail to meet public health standards for ozone. Emissions from petroleum refineries, chemical plants, gasoline stations, and automobiles fill the air with toxic and harmful chemicals to our nation’s environment.

In the late 1980’s, such was the concern for powerful new legislation. Increased air pollution in America’s cities prompted groundbreaking legislation by President Bush. It was designed to continue with new regulations where the Clean Air Act of 1977 left off. In November of 1990, (CAA) addressed three main threats to the nation’s environment: acid raid, urban air pollution, and air emissions. Although today, motor vehicles emit few pollutants ( of up to 80% ) less than cars made in the 1960’s, they account for more than half of the VOC’s (volatile organic compounds) emitted every year. In particular, section 211 of the Clean Air Act provides for new strict regulations on reformulated gasoline. In order to reduce VOC emissions, the reformulated gasoline are required to have a minimum level of oxygenates such as MTBE or ethanol.

The notion of using MTBE for cleaner burning gas has not been a novel concept for gas reformulation. During the 1970’s for the phase out of alkyl lead additives to maintain high octane ratings; MTBE was incorporated as a feasible economic replacement. Ironically, MTBE replaced the alkyl lead additives, already proven at the time to be carcinogenic. Now, through the implementation of the CAA of 1990, MTBE use has increased by leaps and bounds. In 1970, MTBE was the 39th highest produced organic chemical in the United States; today it is the fourth largest at about an aggregate production of 60 million metric tons since 1970. Today, 19 areas in 13 states are involved in the oxylfuel program with the use of MTBE at around 10-15% by volume in reformulate gasoline.

California began its own rules and regulations regarding reformulate gasoline in the 1996. Although the CAA and California regulations do not specify which type of oxygenate to use, MTBE has been the chemical of choice among the oil industry, being favored over the other activities because of its low cost and favorable properties of blending. In 1996, over 85% of gasoline of gasoline in California contained MTBE, with a percent by volume concentrations of up to 11%. This amount equates to 1.5 million gallons of MTBE being consumed in California on a yearly basis.

Environmental Impacts and Health and Safety Risks:

In March of 1993, “Science News” magazine reported on new finding of MTBE’s toxicity and presence in the environment. In Fairbanks, Alaska, after only two weeks of using the reformulated gasoline containing MTBE, more than 200 residents reported of fuel related headaches, nausea, skin rashes and numbness. Citywide protests were instigated, and soon Alaska Governor Walter Hickel was forced to suspend the use of methanol based reformulated gasoline, which included the gasoline additive MTBE. The magazine reported of similar complaints filed in Montana, Colorado, and New Jersey. With the news from Fairbanks, the Center for Disease Control reported that they had found MTBE in the blood content of 18 local residents. Later studies by the CDC showed high evidence that MTBE may be a serious health threat.

Since then, there has been increased detection of MTBE in both ground and surface waters, with numerous studies conducted on toxic side effects and impacts on the environment. A study reported in the magazine, “Science & ideas,” in April 2000, found that as many as 9,000 community water wells in 31 states are threatened by MTBE contamination. In September of 1999, Report of the Blue Ribbon Panel on Oxygenates in Gasoline, stated that between 5 and 10% of community drinking water supplies with high use of RFG MTBE, have detectable concentrations of MTBE. In 1996, a startling discovery found that seven wells supplying more than half the water supply to Santa Monica were contaminated with MTBE, with some areas having concentrations of 600 ug/L (this value exceeding 15 times California’s advisory level of around 20-40 ug/L for taste and odor). In a separate study, the U.S. Geological Survey reported finding MTBE in 21% of groundwater samples taken from known gasoline leakage areas. In the magazine, “Science and News,” in April of 2000, it reported on a study that estimated some 250,000 underground fuel tanks leaking RFG with MTBE in local waterways and aquifer systems. Unfortunately, MTBE is still in use in many areas, with more and more discoveries of contaminated water supplies coming in the news.

MTBE has shown to be a highly toxic chemical. Such novelties have proven it to cause irritation to the respiratory tract if inhaled, central nervous system effects, lightheadedness, dizziness, nausea, and headache. Ingestion may also cause nausea, and vomiting, with laryngeal, ocular, and respiratory muscles being affected in cases of severe poisoning. Furthermore, skin contact may cause loss of natural oils, and a possible means of absorption into the body. These striking and harmful side affects to MTBE arouses increased concern and caution with its widespread use. Several studies have shown a link to cancer among laboratory animals when exposed to MTBE. However, the studies were done under high concentrations of MTBE, and its effect on humans is still unknown. MTBE’s link to gasoline, already a probable carcinogen, makes it difficult to differentiate the carcinogenic effects.

With increased concern and controversy surrounding MTBE, Governor Gray Davis, in an executive order in 1999 finally prohibited the use of the gasoline additive by December 31st, 2002. Several other states have opted to spread in water systems easily and its slow degradation rate, such a ban, if implemented now, could take years to completely remove it form the environment. A scientist form the magazine “Science and Ideas,” reported that if it were banned today, water wells would be threatened until 2010.

MTBE: Methyl Tertiary Butyl Ether:

MTBE, (Methyl Tertiary Butyl Ether), is a synthetic chemical that was developed in the 1940’s. This fuel additive derived from petroleum is a compound composed primarily of carbon and hydrogen atoms. MTBE is classified in the chemical grouping known as “ethers,” which is a class of organic compounds in which an oxygen atom is located in between two carbon atoms: C-O-C. Its official chemical formula is: CH2OC(CH3)3. Ethers are known for their distinct potent, and unpleasant smell, which is why in many contaminated water wells, MTBE’s strong noxious smell could be detected. Ethers are generally soluble in water, with MTBE being very soluble due to a high affinity for water molecules. MTBE, is also highly volatile and extremely flammable. Although it is volatile and has a tendency to evaporate quickly, when in water it has a high affinity for water molecules, and therefore tends to remain in solution.

MTBE’s chemical properties make it an incredibly effective water pollutant. In gasoline spills and leaks, if MTBE encounters water, a large portion will enter. Even among MTBE vapor from gasoline exhaust, when exposed to water, it will be likely to enter as well. This is the reason why many aquifers, water wells, and waterways, have been shown to contain trace amounts of this substance. Unlike traditional gasoline components, which are non-polar and have a low solubility in water, they have never posed a significant threat to the environment in cases of toxic spills; most of the contaminants remain on the surface of the water, never fully integrating itself within the water supply.

Phytoremediation:

In seeing the negative impacts of MTBE, and possible future side affects, one must now look towards solutions. The focus of our study looks at an environmentally friendly application towards solving MTBE contamination.

Phytoremediation encompasses the field of “bioremediation” which employs environmentally friendly methods to clean the environment. It is the direct use of plants for filtering of contaminated soil, sediments, and groundwater, through biological break down of chemical substances, and/or containment and removal. Although it is a relatively new approach towards toxic clean up, it has been successfully proven to “remediate” pesticides, metals, solvents, explosives, crude oil, hydrocarbons, and landfill leachates.

Through the process of phytoremediation, enzymes and exudates from plants have the capability to break down harmful chemicals. Plants can essentially “digest” or metabolize several different toxic organic compounds through their enzymes. Several varieties of plants have been shown useful in this process by employing xenobiotics to break down chemical substances. These enzymes are traditionally used for protection against infections and fungal toxins, but through application of phytoremediation, they can also be used to break up organic compounds. Exudates from plants, which are chemicals secreted from the plant’s roots into the soil, are also helpful. These exudates, usually in the form of sugars, acids, and alcohol’s, can also help break down toxic chemicals.

Significant applications of phytoremediation have proven useful in the field. One study used poplar trees at a contamination site in Oregon. Led by the University of Washington, poplar trees were used to clean out a toxic chemical spill of trichloroethane, which had plagued local drinking wells for years. Poplar trees were introduced to the contaminated soil to filter out the harmful substance. Research had shown that poplars were found to successfully intake up to 97% of the chemical when introduced at the laboratory setting, and that significant amounts of the toxic chemical were removed from the contaminated site. Further laboratory studies have indicated that the tree’s oxidative enzymes can metabolize the trichloroethane and other organic compounds. Other applications of phytoremediation include parrot grass and its ability to remediate contaminated soil with ammunitions wastes. A study conducted by Auburn University tested parrot feather at a sterile site contaminated by high concentrations of TNT (of up to 5000ppm). Within a few weeks time, the introduced population of parrot feather was able to successfully lower the concentrations of the contaminated soil to only 10 ppm of TNT.

Hypothesis/Prediction

In looking at these studies and many others, phytoremediation has many useful applications towards clean up of our environment. Many other plants have proven useful, ranging from potato to rye grass. We hypothesize that plants that have shown to be useful in the filtering of polluted soils and the breakdown of organic pesticides may also show abilities to degrade, decompose, and accumulate MTBE through phytoremediation. In our experiment we chose to work mainly with legumes because of their availability and ease to work with. Although a study by the University of Iowa showed that poplar was successful in phytoremediating contaminated water with MTBE, we hope that our research will offer another approach through the use of soybean and broad bean. We believe that soybean and broad bean may have more useful applications because of their rapid growth and establishment as widely used agricultural crops. Poplar trees might be limited because of their longer growth periods for maturity and large size; logically, a field of beans would be much easier to remove and grow than a grove of trees. In our research, we found that broad bean was found effective for remediation of sulfonamides, and soybean was helpful for benzene’s, insecticides, and hydrocarbons.

However, approaching our experiment was difficult. The main obstacle we faced was that little to nor prior research had dealt with the use of MTBE and phytoremediation. Fortunately, the previously mentioned study on poplar tree cuttings on MTBE proved to be a useful aid. One of the major problems encountered in our experiment was the high volatility of MTBE. When we attempted to weigh out samples of the chemical, the MTBE would evaporate so quickly that the amount used was not accurate. Due to this rapid vaporization, it was not practical to apply it to our experiment. The study conducted by the University of Iowa avoided this obstacle by constructing an air-tight apparatus that would help contain the MTBE. Expanding from their approach, we devised a simpler, yet practical apparatus for conducting our experiment by using an air-tight glass jar, and a Teflon septum membrane for sampling the solution through a syringe. If the plants used in our experiment are effective in the phtyoremediation of MTBE, we should see a greater decrease in MTBE concentration with our plant trials versus our control setup ( consisting of a glass rod in place of the plant).