Contents

I. Abstract

P3 Awards: A National Student Design Competition for Sustainability Focusing on People, Prosperity, and the Planet
Funding Opportunity Number: EPA-G2007-P3-Z3 - Energy
Title: Sustainable Biofuel Systems for Undeveloped Regions
Faculty Advisor: Dr. David Hackleman, Linus Pauling Chair of Chemical Engineering david.hackleman@oregonstate.edu
Institutions: Oregon State University, Corvallis, Oregon
Student Represented Departments and Institutions: Chemical Engineering, Mechanical Engineering, Cell and Molecular Biology, Zoology, Physics
Project Period: September 30, 2007-May 30, 2008
Project Amount: $10,000
Total Project Amount Requested from EPA: $10,000 (Other Contributions: $0)

Project Summary:

While several countries including the US have made significant strides towards implementation of alternative fuels through research and infrastructure development, the areas of the world where they would have the greatest immediate impact on environmental quality - the Third World nations - are often neglected. The goal of the proposed P3 Project is to explore the feasibility of implementing vegetable oil based alternative fuels within the unique social, economic and environmental conditions of these regions. The specific objectives of this project would be to:

1. Identify obstacles to renewable fuel implementation that are specific to developing nations.
2. Investigate which alternative fuel will work best in that environment.
3. Develop sustainable methods of production that work within the limitations.
4. Incorporate traditional knowledge of the target community in production methods.
5. Demonstrate that the method of choice will work with pilot-scale production.

Results will be evaluated based on the level of integration of sustainable methods, feasibility of implementation within the target community, the quality and quantity of fuel produced in the model system and the efficiency of production in relation to fuel needs. Implementation will occur through an interdisciplinary research course emphasizing sustainable technologies. A community in the Pacific Islands has been identified through OSU alumni that will serve as a model, and production will be optimized to the needs of a remote undeveloped community as represented by the model. Particular emphasis will be placed on development of a production method that will be viable beyond the initial project period. Vegetable oil based biofuels meet P3 objectives because they offer the unique possibility of filling the economic need for renewable fuel production, the environmental need of reduced greenhouse gas emissions, and the social needs of environmental education and stabilization of fuel dependency.

Keywords: biodiesel, vegetable oil, pollution prevention, renewable fuels, petroleum, economic barriers, social barriers, technology transfer, enzymatic process, oil extraction

II. Challenge Definition

The lack of sustainable alternatives to petroleum fuels is a critical global concern. Although several alternatives exist, such as biodiesel, ethanol, hydrogen, straight vegetable oil and fuel cell technology, severe technical challenges as well as lack of acceptance by industry and the public have stunted widespread adoption of these innovations in the US and abroad. While several countries including the US have made significant strides towards implementation through research and infrastructure development, the areas of the world where renewable fuels would have the greatest immediate impact on environmental quality - the Third World nations - are often neglected.

The adoption of sustainable alternative fuels in developing nations will have a direct impact on the global climate through protection of the physical environment and preservation of biodiversity. However, the intrinsic constraints on implementation in these areas present both technical and economic challenges including remote locations, few local sources of materials and a need for innovative designs that don't shift negative environmental effects to other locales. The ideal fuel in such a situation would be derived from a readily available, cheap renewable source and would incorporate local cultural knowledge and environmental education in production. One solution that fits these parameters would be a vegetable oil based fuel. This includes biodiesel produced by the traditional transesterification method, novel enzymatic methods of biodiesel production and adaptation of straight vegetable oil. The goal of the proposed P3 Project is to explore the feasibility of implementing vegetable oil based alternative fuels within the unique social, economic and environmental conditions of these regions.

The project would be completed as a case study that could be adapted to almost any specific location. Through Oregon State University (OSU) alumni within the PeaceCorps, we have established a relationship with the village of Narukunibua in Navua District, Fiji. The village represents a real location with particular limitations representative of those in most remote, "undeveloped" areas. The primary use of fuel in the village is to run a diesel generator that provides the only electricity. The specific objectives of this project would be to:

1. **Identify constraints particular to tropical developing nations.** In addition to the limitations of remoteness and lack of available materials, this may include climate, and acceptance of alternatives in the local culture.

2. **Investigate which vegetable oil based fuel will work best.** This includes determining which method will maximize output and minimize the need for costly equipment or complicated procedures that are difficult to implement. Questions to ask include: Are the reagents cheap? Will production meet the needs of the village in a timely manner? Is the method easy to teach? Will the village be able to continue using this method without further instruction or support after the project period?

3. **Develop sustainable methods of production that work within the limitations.** A major obstacle is procurement of a vegetable oil that is harvested in a sustainable way. For example, palm oil is readily available in many tropical regions, is relatively cheap and makes good biodiesel. However, the oil is harvested from oil palm

farms that are created by burning great swaths of rainforest. Incredible erosion and impact on native flora and fauna result, thus palm oil is not a viable oil feedstock.

4. **Incorporate local traditional knowledge.** With the aid of alumni currently living in the village, traditional knowledge of the people will be incorporated into the final solution. One way that the village's traditional knowledge may be useful is in the procurement of an alcohol for the biodiesel transesterification. Import tariffs on alcohol are high in Fiji, yet alcohol can be produced cheaply from local sugarcane.

5. **Demonstrate that the method of choice will work.** Fuel samples will be produced under simulated conditions, and ultimately, at the test site. Not only must the procedure of choice provide useable fuel, it must be easy to teach to the villagers and easy to incorporate into the daily routine.

III. Innovation and Technical Merit

This project will integrate traditional local knowledge of indigenous peoples with technological innovations that allow local production of sustainable fuels. Many indigenous cultures already possess knowledge of sustainable techniques for oilseed crop farming, oil extraction, and alcohol fermentation which are all necessary for biofuel production. With the aid of recent technical innovations in biodiesel production and oilseed extraction developed at Oregon State University and elsewhere, development of a complete system for sustainable fuel production in remote areas with limited resources, and limited abilities to import materials will be developed.

We will investigate a wide range of techniques for oil extraction and fuel production including (but not limited too) mechanical oil extraction, on site alcohol production, batch process biodiesel reactors, enzymatic biodiesel reactors, and straight vegetable oil as a fuel. A brief description of each of these techniques is provided below:

1. **Mechanical Oil Extraction:** Diverse oil extraction methods will be evaluated in conjunction with various oil bearing crops. Due to health and environmental hazards associated with chemical extraction, a mechanical method will be sought. Expeller pressing, screw pressing and ram pressing are all under consideration. Expeller pressing uses a continuous feed system that gradually increases the pressure on the seed until oil is extracted. Screw and ram pressing use similar methods of increasing pressure. Extraction methods which use human physical force and/or rotational or electrical energy produced by an alternative fuel powered engine will be used. The process for oil extraction will be designed through a collaborative effort of the Chemical and Mechanical engineering departments at OSU as well the Crop and Soil Science department.

2. **On site Alcohol Production:** A practical method will be developed to produce an alcohol reagent, critical to the transesterification process used in making biodiesel. The production of alcohol in an underdeveloped community will utilize local resources to assure sustainability. Traditional low cost fermentation methods will be assessed for practicality. Alcohol can be produced by fermentation from a number of different plants

containing sugars. Plants indigenous to the regions of interest for biofuel production will be evaluated against sustainability and output potential. The process for fermentation will be designed through a collaborative effort from the Oregon State University Agriculture Science, Chemical Engineering and Mechanical Engineering departments.

3. **Batch Process Biodiesel Reactors:**

   In a “traditional” batch process biodiesel reactor, transesterfication (the conversion of vegetable oil and alcohol into biodiesel and glycerine) takes place in the presence of a strong base that acts as a catalyst allowing the reaction to progress. Alcohol and catalyst are first mixed in a separate smaller tank, and then slowly mixed with vegetable oil in the reactor. After mixing is complete, the glycerine and catalyst settle to the bottom where they can be easily separated from the biodiesel. The glycerine byproduct and catalyst are pumped off the bottom, and the biodiesel is ‘washed” by agitating it with water to remove the leftover alcohol. When the washing is complete, the biodiesel layer above the water can be filtered and used as fuel in a diesel engine. This process is the best known and most widely used method of biodiesel production, and the reactor itself can be built cheaply from commonly available parts. It requires larger quantities of high purity alcohol and catalyst than other methods, and the leftover alcohol and catalyst are difficult to recover and reuse; therefore utilization of this method is contingent on the local availability and affordability of these materials.

4. **Enzymatic Biodiesel Reactors:** Enzymatic production of biodiesel has been demonstrated to be efficient and cleaner than conventional processes [7][11]. Recent intensive research on this novel method has yielded promising avenues that require consideration [12].

   Enzymes are proteins that catalyze chemical reactions. In the biodiesel reaction, enzyme catalysts act similarly to inorganic catalysts (such as lye or potassium hydroxide) and result in the same products, but with a different mechanism at the molecular level. As with all catalysts, the enzymes are regenerated through the reaction. Several enzymes of fungal and bacterial origin, which are generally termed lipases, have been proven to efficiently catalyze the biodiesel transesterification reaction under a range of conditions. A key advantage to this method is the replacement of the costly and toxic catalyst required for “traditional” biodiesel production with non-toxic, organic proteins. Synthesis with this method has been demonstrated for numerous oils, including coconut, canola, soybean, sunflower, rice bran, oil palm kernel, even fish oils and beef tallow [1][2][5]. Both and methanol are commonly used in the enzymatic method [2]. Some catalytic enzymes don’t require very pure alcohol, allowing the use of lower quality alcohol that is produced on site. Costly import tariffs on alcohol, as well as complex distillation procedures could thus be avoided.

   Possible enzymes that fit the needs of this project include *Candida antarctica* (CALB, Novozyme-435), *Pseudomonas cepacia* (Lipase PS-30), *Pseudomonas fluorescens* (Lipase AK), and *Rhizopus oryzae*[2][7][8][10][11][13][17]. Enzyme efficiency varies depending on water content of the mixture, the type and purity of alcohol used, and whether the reactions are done in the presence of an organic solvent. Additional research must be completed before the application of a particular enzyme to this challenge may be addressed.

The enzymatic method does have several drawbacks that may present challenges for the team. Generally, the activity of catalytic enzymes decreases precipitously after each use, causing reaction rates to decrease over time. To counter this, several protocol modifications will be examined that aid in enzyme recovery for the next reaction, such as washing the enzyme with isopropanol or fixing it to a substrate inside of the reactor [5][12][16]. Such recovery also combats the other major drawback of lipases - expense [2][3][4][9].

Although enzymes are safer and more environmentally friendly, several barriers would have to be overcome to make their use economical for this application. A robust system to produce biodiesel enzymatically in developing areas of the world needs to be flexible and allow for variability in the oils, alcohols, and water content used in the reaction, thus a combination of lipases might be desirable. Given that the necessary oil feedstocks are already present in Fiji, the enzymes may be produced in simple bacterial or yeast fermenters. Lipases are also available commercially.

Oil type, alcohol purity and enzyme are all key factors in the assessment of the feasibility of enzymatic syntheses in underdeveloped areas of the world.

5. **Straight Vegetable Oil as a Fuel:** An alternative to converting vegetable oil to biodiesel is to use the vegetable oil directly as fuel for a diesel engine. Diesel engines require low viscosity (thin) oils for fuel. Most diesel engines will run well on any oil that is 20 cSt (centistrokes) or lower (thinner). At normal operating temperature diesel fuel is under 5 cSt, and biodiesel is under 6 cSt making them both suitable fuels. Vegetable oil, however is about 30 cSt, which can cause damage or prevent the engine from running. By heating the vegetable oil over 160 degrees F it can be thinned enough to allow the engine to run flawlessly[14]. One way to do this is to start the engine on regular diesel fuel, and use the engine coolant to heat the vegetable oil through a heat exchanger as it warms up. Once the oil reaches a temperature where it is thin enough to use as fuel, the engine is switched over to the heated oil, and then switched back before shutdown so that it can start the next time on regular diesel fuel. This method still requires use of a small amount of diesel fuel for startup and shutdown, but eliminates the need for the equipment and supplies required for biodiesel production. Several members of the OSU Biodiesel Initiative have successfully designed, built, and used vegetable oil heating systems on diesel engines.

A "traditional style" Biodiesel reaction requires the use of a strong base as a catalyst, and high purity alcohol. Typically methanol is purchased from a chemical supplier. Methanol purchased in this way is expensive, difficult to obtain in remote areas, corrosive, and has high toxicity to humans. While this type of biodiesel reaction can be done with ethanol, the ethanol must be of high purity, which is difficult or impossible with traditional distillation procedures. Our case study is a very remote location, thus a system requiring regular importation of consumables such as alcohol and catalyst is impractical. An innovative biodiesel process that either avoids the use of these consumables altogether, or produces them on site is required. The enzymatic biodiesel and straight vegetable oil techniques are prime candidates for self contained community fuel production. The advantages and disadvantages of each of these techniques will be examined, and the one that is best suited to our design parameters will be chosen.

IV. Measurable Results and Evaluation Method

Results of the project will include development of a protocol for vegetable oil based fuel production that meets the specific needs of the target community. This will be accomplished through measurement of fuel production efficiency and quality with the proposed method, measurement of generator efficiency with various fuel alternatives and assessment of protocol acceptability by the village community.

1. **Quality of fuel.** The quality of fuel produced will be determined by the American Society of Testing and Materials' biodiesel specification (ASTM D6751). Student research projects will involve determining operating protocols for each proposed fuel alternative that meet the appropriate standards.
2. **Fuel/Generator efficiency.** The operational efficiency of the test setup with various fuel mixes and operational conditions will be determined by production rates, necessity for chemical additives such as enzymatic or caustic catalyst.
3. **Sustainable Methods.** Sustainability of the production protocol will be measured by creation of a "Sustainable Practices Map" that traces the source and production method of every input into the design (oil, alcohol, enzyme, etc) as well as the use and/or destination of every output (fuel, glycerin, other waste).

The success of the project will be evaluated in accordance with the measurable results. Creation of a method that produces quantities of fuel large enough to meet the village demand, which can me easily measured, as well as producing high-quality fuel that meets ASTM standards, which can also be easily measured by students once they are familiar with relevant test procedures, is critical.

V. Implementation Strategy

OSU has a strong alternative fuels focus and supporting community. Previous institutional research related to biodiesel has included comparisons of the ecological and economic effects of different oil feedstocks in the Pacific Northwest through the College of Agriculture, studies of the enzymatic method of production by algae in the College of Science and development of novel production mechanisms and uses for byproducts in the College of Engineering. Students from all three colleges will be actively involved in this project. In addition, students with backgrounds in anthropology, ethics and environmental policy will participate. The existing foundation will provide a support network for the P3 Team as well as guidance in research, development, technology transfer and synthesis of social and economic objectives.

The essence of the proposed project is to build a sustainable system, then examine the feasibility of adoption at the test site. Implementation may be divided into 5 categories: identifying constraints, investigation of fuel solutions, development of sustainable production methods, the incorporation of cultural knowledge and demonstration of the developed system. Initial identification of constraints will occur in conjunction with our alumni contact in the field. After formulating a comprehensive list of factors affecting fuel production and use, the team will research the positive and negative aspects of various vegetable oil based fuels in regards to the known limitations. Preliminary lab research on the practicality of the various fuel options will be conducted by students as part of an upper division undergraduate course in sustainable engineering, administered through the Chemical Engineering department. Research will be synthesized into a report that concludes which fuel strategy is best suited to our case study and outlines a plan for the next stage. The report will then be submitted to the university administration for approval to ensure full compliance with all safety regulations before going ahead with larger scale fuel production.

Reactors and workspace will be provided by the Chemical Engineering Department, and a diesel generator will be provided by the Mechanical Engineering Department to run fuel samples under simulated conditions. Consistent and reliable methods of fuel production will be developed. Throughout the project period the team will meet bi-weekly to review progress, brainstorm solutions to the inevitable obstacles and create an outline for the next weeks' activities. Communication with our alumni contact in Fiji by e-mail will occur throughout the project period.

VI. Sustainability

Sustainability is defined as "meeting the needs of today without compromising the ability of future generations to meet their needs"[15]. Thus, resource conservation, limiting waste production and planning for the future are all central concepts. Sustainability is often colloquially defined as meeting the triple bottom lines of economic, environmental and social needs. Vegetable oil based biofuels offer the unique possibility of filling the economic need for renewable fuel production, the environmental need of reduced greenhouse gas emissions, and the social needs of environmental education and stabilization of fuel dependency.

Because sustainability of human-environmental interactions are relative to a particular time and place, research and experimentation performed at OSU will attempt to replicate conditions at the test site to the highest degree possible. The fuel production protocol will incorporate equipment such as low cost hand operated oil crushers which are easy to use and produce no unusable waste. Consumables will be kept to a minimum, and practical applications for waste will be sought, such as using waste glycerin from biodiesel production as a fertilizer for village crops.

The onsite village production of liquid biofuels promotes a variety of sustainability factors. Exposure to such alternatives will provide community members with a greater awareness of and connection to sustainability. The utilization of local raw materials for immediate conversion provides a secure energy future for the village. A native crop, such as coconuts, will provide the oil source and education on sustainable harvesting methods will be incorporated into the final protocol. Coconut palms are native to Fiji and can be grown and harvested in a renewable way, unlike the oil palms which are invasive species. Locally produced biofuels will eliminate or reduce the need to purchase diesel fuel from outside sources. This elimination decreases village expenditures and potentially increases economic independence and reliability of fuels. Employment opportunities will also be created as village members learn to manage and produce their own fuel supply. This increases their skill set, raising individual sustainability concurrently with that of the village.

Vegetable oil based biofuel production and usage will also positively impact villager's health. Studies in the US have shown that the sulfur content in diesel has carcinogenic effects on humans [6]. By comparison, the combustion of biodiesel or vegetable oil drastically reduces the amount of harmful pollutants released into the environment. This is especially important within the model of a remote undeveloped community, as recurring exposure to noxious diesel fumes are likely due to the necessary proximity of the diesel generator to homes in the village.

VII. P3 Concepts as an Educational Tool

Education is essential to the technical, environmental and cultural elements of this project. Individual student research, contribution to the alternative fuels curriculum at Oregon State University and networking between diverse student groups are all crucial to success.

OSU undergraduates in the College of Engineering, College of Science, Honors College and other programs will have the opportunity to produce their own senior thesis research projects based on various technical aspects of the research plan, and receive course credit for their work. This will be achieved through an interdisciplinary research course for upper-division undergraduates administered through the Chemical Engineering Department. The course will facilitate deeper thinking on energy issues and sustainability while emphasizing creative problem solving.

In addition, students will learn about energy concerns at the regional, national and global levels through the development of an Alternative Fuels Forum to be hosted by the university and put together by the OSU Biodiesel Initiative. Speakers from both within and outside the university will present on various aspects of implementing biofuels. Organizing such community outreach events will give students an opportunity to articulate their newly acquired knowledge while informing others, both inside and outside of the academic community, about sustainability concepts.

VIII. Project Schedule

The following Gantt figure will be used to track project development and keep team members informed of upcoming events. The major co-investigators will be involved with each aspect of project development, including feasibility research, process design and method demonstration. OSU Biodiesel Initiative Group meetings will be run by the P3 Team but are open all students, faculty and community members who wish to attend. Throughout the project period bi-weekly meetings will occur. Major tangible outcomes include a report that summarizes all preliminary research, a publishable protocol for alternative fuel production in undeveloped nations and a "Sustainable Practices Map" that traces all inputs and outputs of the process. Objectives for each term of the project period are detailed below:

Project Objectives for Fall 2007 Preliminary Research

- Identify a reliable, sustainable oil source
- Explore oil extraction methods: Screw press, ram press, expeller press
- Research economics of oil heating method
- Literature search
- Note possible safety concerns
- Determine relative purity of alcohol produced onsite, compare to importation or other procurement routes
- Research which enzyme would work with the purity of alcohol available
- Decide on a recovery method for enzyme (if this process is pursued)
- Begin Sustainable Practices Map

Project Objectives for Winter 2007 Design and Development

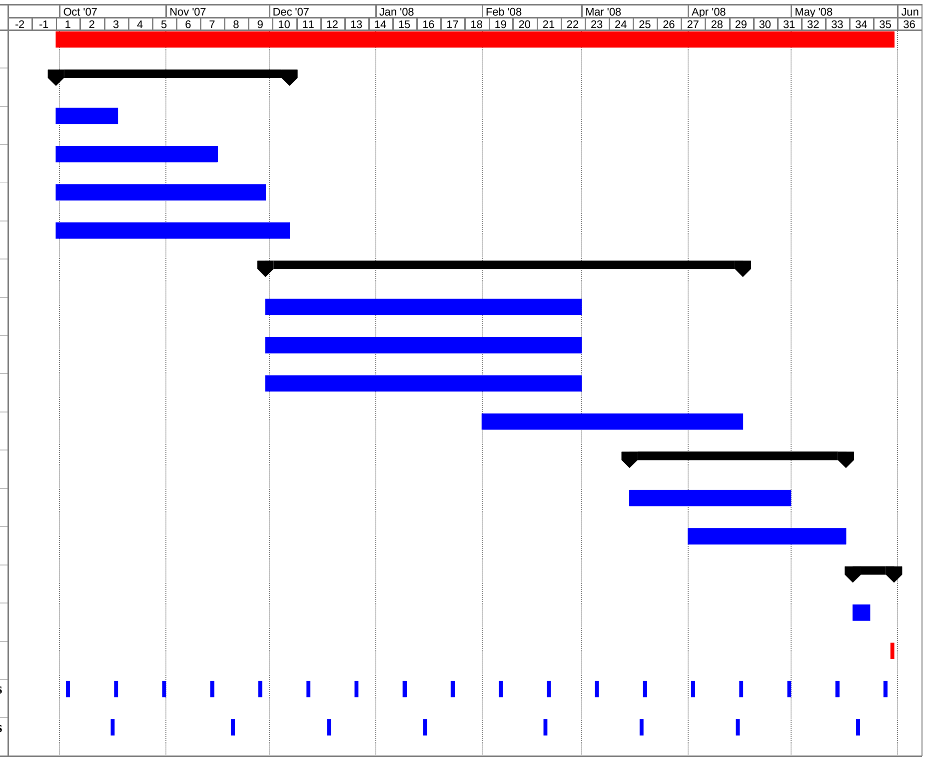
- Decide on an oil extraction method
- Decide what alcohol will be used
- Decide a primary fuel production method to be pursued
- Produce a report that summarizes research and recommends a protocol, submit fo university approval
- Continue Sustainable Practices Map
- Design and order components for the reactor
- Maintenance generator and begin generator optimization tests
- Continue fuel sample test runs

Project Objectives for Spring 2007 Development and Demonstration

- Fine tune reactor setup
- Test fuel quality, record reaction rates
- Finish Sustainable Practices Map
- Unveil design to OSU and community
- Attend National Sustainable Design Expo, Washington, D.C.

P3 Phase I Project Schedule

Task Name	Duration
Phase I Project Period	177 d
Feasibility Research	**10 wks**
Vegetable Oil Heating	14 d
Oil Extraction Process	35 d
Onsite Alcohol Production	45 d
Enzymatic Biodiesel Reactor	50 d
Design	**20 wks**
Oil Extraction Process	66 d
Onsite Alcohol Production	66 d
Biodiesel Reactor	66 d
Design integration	55 d
Develop	**9.2 wks**
Purchase System Components	34 d
Manufacture Mock Up	34 d
Demonstrate	**2 wks**
Roll Out Design to OSU Community	5 d
National Sustainable Design Expo	1 d
OSU BioDiesel Initiative Group Meeting	**34.4 wks**
Core System Design Group Meetings	**31.4 wks**



IX. Partnerships

While this project has been developed specifically by students of the OSU Biodiesel Initiative, the P3 Team will collaborate with multiple partners both on and off campus.

On campus partners:

- Student Sustainability Initiative
- Faculty Sustainability Initiative
- Associated Students of Oregon State University - Environmental Affairs Task Force
- OSU Chapter - Engineers Without Borders
- OSU Chapter - American Institute of Chemical Engineers
- Oregon State Alumni Association

Off campus partners:

- The Corvallis Sustainability Group
- U.S. Department of Agriculture - Agricultural Research Station, Corvallis OR
- USA PeaceCorps (letter of intent attached)

X. Budget

	Category	Cost $
	Travel Costs:	
A	Airfare from Portland, OR to Baltimore, MD	405
B	Lodging in Washington, DC	100/night x 3 nights = 300
C	Ground Transportation within Washington, DC	100
D	Total per Student	805
	Travel Total	805 x 3 = 2415
	Supplies:	
A	Office Supplies	0
B	Laboratory Supplies	2250
C	Processing Equipment	2175
	Total Equipment Costs	4650
	Total Project Cost	6840
	Indirect Charges	3160
	Total requested from EPA	**10000**

XI. Budget Justification

Travel

A. **Airfare:** Ticket costs were estimated from general figures found through online searches. Students will pay for their own transportation to the Portland International Airport (PDX). The faculty advisor will be supported by university and/or personal funds.

B. **Lodging:** Costs were estimated from general figures found through online searches.

C. **Ground Transportation:** Costs are based on one Amtrak ride from the Baltimore Airport to Washington, D.C. (Amtrak.com) and one taxi ride per student to the hotel.

D. **Total per Student:** Three Students are expected to participate in the P3 Award Event and design expo in May 2008. Thus all travel expenses are multiplied by three.

Supplies

A. **Office Supplies:** Will be provided by the Chemical Engineering Department.

B. **Laboratory Supplies:** All necessary research supplies and equipment, including chemical reagents and enzymes, instruments, instrument repair, safety equipment and analytical tools. An itemized list is presented below. Costs were determined by consultation of lab supply catalogs, discussion with technicians of the Chemical Engineering Department, and online searches.

Laboratory Supplies	Cost $
Vegetable Oil Samples	120
Ethanol, Methanol, Alcohol Blends	200
Enzymes and enzyme mixes	900
Inorganic catalyst	200
Glassware	145
Safety equipment	55
Fuel Quality Analysis Reagents	630
Total	2250

C. **Processing Equipment:** No individual items costing $5000 or more are required for this stage of the project.

XII. Appendix

OSU Alumni Isaac Sunderland (lower center) with traditional Fijian warriors in Narukunibua, Fiji.

XIII. Bibliography

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XIV. Letter of Intent

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XV. Faculty Resume