Valley 25x'25 Project

Shenandoah Valley as a National Demonstration Project Achieving 25 Percent Renewable Energy by the Year 2025

Final Report

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Executive Summary

Valley 25x'25 was created to promote renewable energy and energy efficiency in the Shenandoah Valley. Taking our name from the U.S. government's stated goal of 25 percent renewable energy by the year 2025, and from the national 25x'25 renewable energy advocacy organization, Valley 25x'25 seeks to support sensible renewable energy implementation and research in the Shenandoah Valley. Housed at James Madison University (JMU), Valley 25x'25 has primarily focused its efforts in the central Shenandoah Valley, though its impacts have occasionally had a broader reach throughout the Valley, the Commonwealth of Virginia, and beyond.

In 2009, Valley 25x'25 received a federal appropriation to help advance its mission and to establish itself as an East Coast demonstration area for how the U.S. can achieve the 25 percent renewable energy by 2025 goal. During the subsequent four years, the Valley 25x'25 team has worked in a variety of contexts to help promote this goal and to foster research and outreach associated with renewable energy and energy efficiency. Though we are still well short of our 25 percent goal, our efforts and our careful use of federal funding has contributed to a wide variety of worthy projects that are detailed in this report.

In the area of project implementation, Valley 25x'25 focused on pilot, university-based projects, since it would not have been appropriate to funnel federal monies to underwrite private projects. Among the notable pilot projects is a biochar installation at a local farm, which will help to produce energy, increase agricultural productivity, and sequester carbon. This technology is a promising one, and a JMU faculty member is involving students in studying the design, use, and implementation of biochar systems, with a special interest in poultry litter as a potential fuel source.

Much of the work that Valley 25x'25 supported focuses on applied research and studies of implementation. For example, one mini-grant recipient looked at the actual (comparison to advertised) performance of electric vehicles. One of the Valley 25x'25 leaders, Dr. Chris Bachmann, worked with a student to assist a Valley company seeking to improve the efficiency of diesel engines using a novel water-injection technology for diesel engines aimed at reducing emissions and increasing fuel economy. Here, Valley 25x'25 has provided a key role of serving as a neutral party examining the validity of the claims made by the developer of the technology.

Valley 25x'25 has also provided funding for a wide range of more research-based projects that explore short-term and long-term technologies for renewable energy. For example, we provided funding to Green Impact, a group seeking to advance energy efficiency through the implementation of a web- and mobile-device-based application for doing a basic home or business energy use evaluation (audit), which is currently in use. Longer-term projects have included the exploration of algae for use in the production of diesel fuel, research into the use of solar energy for hydrogen fuel production, and the exploration of non-battery energy-storage devices for home-scale use. The vast majority of these projects have included students or former students as active participants, which contributes to the long-term impact of the projects.

Finally, much of Valley 25x'25's activities have been in the area of outreach and community partnerships. Members of the Valley25x'25 team have attended numerous community events over the past four years, including energy- or sustainability-related events, but also extending to events that appeal broadly to the general public. Of particular note is a forum on poultry-litter-to-energy systems that Valley 25x'25 organized and hosted in February 2012. The event, which drew over 125 attendees, featured representatives from different companies selling such systems, political leaders, and farmers with knowledge of and experience with these technologies. We also built a website containing useful information about renewable energy issues and topics with a special focus on topics of interest to Valley residents, www.valley25x25.org. Finally, Valley 25x'25 was a founding member and early leader of the Harrisonburg Rockingham Green Network, an affiliation of sustainability-focused organizations that continues to be actively involved with renewable energy issues in the central Shenandoah Valley.

The Valley still has a long way to go to reach 25 percent renewable energy, and it will be a serious challenge to do so by 2025. This is particularly true given the substantial drop in oil and natural gas prices during the past few years, which makes the position of renewables even more challenging, especially in an area like the Shenandoah Valley in which most consumers value the financial bottom line over long-term environmental issues. Yet the federal funding helped Valley 25x'25 to make some important progress in promoting renewable energy along with energy efficiency in the region, and in performing valuable research on small-scale, innovative energy projects with both short-term and long-term development horizons.

Background

Led by James Madison University, Valley 25x'25 promotes using a diverse energy portfolio to achieve the goal of 25 percent renewable energy by 2025, including renewables like wind, biomass, solar, and geothermal. A primary emphasis is energy efficiency, which offers the best opportunities to decrease the use and impact of non-renewable energy sources. Endorsed by the national 25x'25 organization, Valley 25x'25 serves as an East Coast Demonstration Project, and as such, partners with regional businesses, local and state governments, institutions of higher education, and K-12 schools to explore how Valley resources can contribute to the development of innovative energy solutions.

A central goal of Valley 25x'25 is to educate and inform Valley residents about renewable energy opportunities. Other goals include advocacy for policies that incentivize and enable renewable energy projects and for streamlining local and state ordinances, building codes, and regulations to facilitate more rapid introduction of new technologies. Encouraging public acceptance and adoption of sensible and environmentally sustainable renewable energy technologies is the single most important contribution we can make toward the long-term prosperity of the region and country.

<u>Participants</u>

Kenneth Newbold, PI, JMU Director of Research and Innovation

Chris Bachmann, Co-PI, JMU Associate Professor of Integrated Science and Technology

Jeffrey Tang, Co-PI, JMU Associate Dean of the College of Integrated Science and Engineering

Benjamin Delp, JMU Associate Director of Research Development

Ryan Cornett, Outreach Coordinator, Virginia Clean Cities

Becky Rohlf, Fiscal Technician, JMU Office of Research and Scholarship

Craig Honeycutt, Valley 25x'25 Outreach Coordinator

Nathan Miller, Valley 25x'25 Research Assistant

Elise Lintelman, Valley 25x'25 Research Assistant

Garrett Stern, Valley 25x'25 Research Assistant

Sallie Drumheller, Print Production Assistant, JMU Office of Research and Scholarship

<u>Objectives</u>

- To leverage current grant activities and products with related university capabilities and programs to seed faculty research projects in transportation, energy efficiency, sustainable buildings, and energy production;
- To partner with local farmers, businesses, entrepreneurs, etc. on energy projects that address the four above mentioned focus areas;
- To implement a robust outreach program with the community to educate the citizens of the Shenandoah Valley on renewable energy strategies and policies that are economically viable and environmentally sustainable;
- To create an information clearinghouse on renewable energy and energy efficiency funding opportunities, news, permits, legislation, events, and other useful information to

assist Valley residents in transitioning to the green economy and green lifestyles through a website; and

- To produce data that will allow Valley 25x’25 to better understand the challenges to reach the 25 percent goal well in advance of the deadline, and provide replicability for other regions.

Research

Internal Request for Proposals

In order to spur alternative and renewable energy research at host institution James Madison University, the Valley 25x’25 team released a request for proposals (RFP) for JMU faculty and students in 2011 and 2012. Awarded projects consisted of faculty-student teams, addressed a variety of topics and challenges, and emphasized interdisciplinary collaboration. Ten of the following research projects were funded as a result of the RFP.

Long-term Research

Achieving the 25 percent renewable energy goal will require a strategy employing multiple energy generation technologies and energy saving practices. With continued development and increases in the global population, new advances in renewable energy systems will need to occur to meet increasing demand. In a single minute, enough solar energy strikes our planet to power the mechanized world for an entire year – but at present we are unable to capitalize on this resource. Clearly, solar energy presents the most promising long-term solution for providing abundant, affordable energy for generations to come, but current solar energy collection and storage are inadequate. As part of the Valley 25x’25 research arm, several long-term endeavors have been initiated to help advance both energy collection and storage. All of these research areas have tremendous potential to provide clean, renewable energy well beyond the exhaustion of conventional fossil fuels. (Full reports can be found in the appendix.)

A Tool to Assess the Sustainability of Poultry Litter to Energy Systems
Adebayo Ogundipe, Assistant Professor of Engineering

Materials for Solar Hydrogen Production and Next-Generation Photovoltaic Cells
S. Keith Holland, Assistant Professor of Engineering
David Lawrence, Professor Emeritus of Integrated Science and Technology

Two-Phase Energy System
Jacquelyn Nagel, Assistant Professor of Engineering
Student: J. Ben Condro

Short-term Research

Although it is not possible to make an immediate transition and displace fossil fuel consumption with renewable energy on a massive scale, there are many opportunities to reduce consumption and implement renewables on a smaller, local scale. As part of the Valley 25x’25 implementation and demonstration component, several of these strategies have been undertaken to show the public that there are technologies that exist now that can move society towards a cleaner energy future. (Full reports can be found in the appendix.)

A System Dynamics Analysis of the growth in Virginia's Residential Electricity Consumption trends, 1980-2010

Michael Deaton, Professor of Integrated Science and Technology
Student: Raguram Sellakkannu

Algae: Tomorrow's Bio-fuel

Chris Bachmann, Associate Professor of Integrated Science and Technology
Students: Caleb Talbot and Premal Patel

Assessing the Practicality of Implementing a Nutrient Trading Program in the Shenandoah Valley

Jeff Tang, Associate Dean of the College of Integrated Science and Engineering
Student: James Sheats

Biodiesel Research and Development
Chris Bachmann, Associate Professor of Integrated Science and Technology
Students: Bernard Newman, Scott Teigeler, and Jeffrey Wiggins

Biodiesel Safety and Recommendations, Procedure Manual, and ASTM Biodiesel Standard Testing Analysis

Chris Bachmann, Associate Professor of Integrated Science and Technology
Student: Parker Helble

Construction and Implementation of a Pyrolysis Unit for the Production of Biochar in a Sustainable Greenhouse Heating System

Wayne Teel, Professor of Integrated Science and Technology
Students: Amanda Martindale, Dorottya Spolarics, Julianne Decker, and Marlee Winnick

Development and Implementation of an On-Campus GPS Bike Sharing Program

Anthony Teate, Professor of Integrated Science and Technology

Education and Engaging Local Organizations, Community Members, and University Students through an Energy Efficiency and Sustainable Buildings Community Outreach Program

Carol Hamilton, Lecturer of Management
Students: Daniel Hill and Dave Hussey

Electric Vehicle Energy Usage Modeling, Simulation, and Testing for Range Estimation

Robert Prins, Associate Professor of Engineering
Students: Lee Winslow and Robbie Hurlbrink

Preliminary Performance Analysis of NoNOx Water Fuel Emulsion Device

Chris Bachmann, Associate Professor of Integrated Science and Technology
Student: Joseph Crosbie

Researching and Implementing a Policy to Promote Sustainable Energy in Virginia
Jeff Tang, Associate Dean of the College of Integrated Science and Engineering
Student: Ryan Ramirez

Reducing the Cost of Biodiesel Production in the Shenandoah Valley
Chris Bachmann, Associate Professor of Integrated Science and Technology
Students: Jonathan Hawkins and Jason McNamara

Renewable Electric Conversion and Demonstration Project
Alleyn Harned, Executive Director of Virginia Clean Cities

Valley Geothermal Project
Tony Hartshorn, Assistant Professor of Geology and Environmental Science
Students: Jeremiah Vallotton, Fernando Perez, and Elizabeth Weisbrot

Publications

No Silver Bullet: Options and Challenges in Energy for Transportation
The CIP Report, George Mason University
Jeff Tang, Associate Dean of the College of Integrated Science and Engineering
Chris Bachmann, Associate Professor of Integrated Science and Technology

Distributed Energy Resources (DER) to Mitigate Energy Sector Vulnerabilities
The CIP Report, George Mason University
Ben Delp, Associate Director of Research Development
Nathan Miller, Valley 25x'25 Research Assistant

Oil and Gas Boom and the Future of Energy in the United States
The CIP Report, George Mason University
Jeff Tang, Associate Dean of the College of Integrated Science and Engineering

Capturing Heat from a Batch Biochar Production System for Use in Greenhouses and Hoop Houses
Journal of Agricultural Science and Technology
Wayne Teel, Professor of Integrated Science and Technology

Research Reviews

Valley 25x'25 held Research Reviews on October 10, 2011, and October 24, 2012, in order to showcase the research generated during the summer of 2011 and 2012 to members of the campus and local community. The 2011 event featured 12 presentations of Valley 25x'25-funded projects. More than 50 participants from across the university attended the event, which was featured in both the school and local newspapers. The 2012 event drew more than 60 participants from across the university, as well as community members interested in energy and sustainability research at JMU. (Full programs can be found in the appendix.)

Academics

<u>Curriculum Development</u>

Integrated Science and Technology 480/580: Renewable Energy for the Shenandoah Valley

This course provides students with an understanding of energy consumption, use, generation, and economics for transportation fuels, and electrical power from both traditional and renewable energy sources. It introduces students to the thermodynamics of power generation, land use, regional development and planning, and carbon accounting for current technology and generation processes. Students will also be actively engaged in evaluating how the Shenandoah Valley region could generate 25 percent of its energy needs by 2025, by defining the scope of area; evaluating social, political, and land use areas; examining current technology availability, costs, and practicality. The emphasis is on determining a sustainable and appropriate paradigm that would allow the Shenandoah Valley region to meet or exceed the goals of Valley 25x'25, with respect to balancing current social, political, and technological constraints. The course provides a medium to introduce basic knowledge and allow students to use critical thinking skills in a team format to develop problem scope, evaluate pros and cons of potential solutions, and develop an integrated plan for implementation. Lectures will introduce topics and methods of application, and often incorporate outside speakers from industry. Several optional field trips to project locations will be offered. (Mid-term report can be found in the appendix.)

<u>Lectures</u>

Virginia Tech Cooperative Extension Public Education Class (2009)

Evening course on how to make biodiesel with lab-style hands-on demonstrations.

JMU Institute for Stewardship of the Natural World Continuing Education Course (2009)

Lecture on greening your car.

Peak View Elementary School (2009)

Lecture on alternative fuels.

Institute of Electrical and Electronics Engineers JMU Student Chapter (2010)

Guest lecture.

JMU Honors Program Special Lecture (2010)

Presentation to students residing in the Honors Dormitory: What you can do to be more energy efficient.

JMU History of the Automobile class (2010)

Guest lecture.

Public Policy Master's Program (2011)
Guest lecturer on ethanol policy during brown-bag lunch seminar series.

Harrisonburg High Governor's School STEMinar Series (2013)
Presented at the Harrisonburg High Governor's School STEMinar kick-off, an event designed to motivate middle school students to pursue studies in STEM fields.

JMU Lifelong Learning Institute (2013)
Delivered lecture on Valley 25x'25 program.

<u>Senior Capstone Projects</u>

***SuperMileage Vehicle* (2010)**
Students: David Roy, JT Danko, Danny Yeh, Ben Akiyama

BioHydrogen Production and Hydrogen Vehicles (2010)
Students: Dan Attard, Andrew Spurr, Taylor Moellers, Dan Knox, Ellis Gore, and Vincent Zampelli

Electric Vehicle Conversion (2011)
Students: Drew Loso, Justin Stevens, John Bucci, Nick Kerschl, and Timmy Austen

Understanding Urban Growth, In-fill, and other Smart-growth Strategies (2011)
Student: Gareth Herman

American Motorcycle, American Fuel Project (2012)
Students: Josh Magura, Jared Roberts, Tim Teague, Billy Copely, Kyle Clerico, Taylor Balac, Brady Allen, Brandon Greene, and Robert Rominaw

Solid-phase Catalyst for Biodiesel Production (2012)
Students: Scott Teigeler, Jeff Wiggins, and Bernard Newman

Algae-based Biofuels (2012)
Students: Jackson Adolph and Mike DePaola

Biodiesel Gas Chromatography (2013)
Students: Jon Hawkins and Jason McNamara

Evaluation of Water/Fuel Emulsion System (2013)
Student: Joe Crosbie

Novel Strategy for Extracting Algae-Oil from Seawater (2013)
Students: Caleb Talbot, Premal Patel, Sarah Gibson, Kerrianne Bertolino, Remy Biron, and Britton Cocke

Assessing the Practicality of Implementing a Nutrient Trading Program in the Shenandoah Valley (2013)

Student: James Sheats

Outreach, Service, and Engagement

<u>Conferences and Professional Events</u>

Commonwealth of Virginia Energy Symposium (2009)
Oral Presentation and Session Moderator
Chris Bachmann, Associate Professor of Integrated Science and Technology

Virginia Renewable Energy Conference (VAREC) (2009)
Participant

25x'25 National Summit (2009 and 2010)
Participant

Valley 25x'25: Sustaining and Creating Green Economy in the Shenandoah Valley (2010)
Presentation
Jeff Tang, Associate Dean of the College of Integrated Science and Technology

Environment Virginia, Lexington, VA (2010, 2011, 2012, 2013)
Booth Exhibitor

Harley-Davidson/MillerCoors Partnership for Alternative Fuel Engine Optimization
Students: Josh Magura, Jared Roberts, Tim Teague

Reducing Environmental Impact Through Innovative Biodiesel Research, Development, and Implementation
Students: Jeff Wiggins and Scott Teigeler

Algae-based Biofuels: Turning a Problem into a Solution
Students: Jackson Adolph and Mike DePaola

Performance Evaluation of Water/Fuel Emulsion Device
Student: Joe Crosbie

Reducing the Cost of Biodiesel Production in the Shenandoah Valley
Students: Jon Hawkins and Jason McNamara

Novel Harvesting Strategies for Algae-based Biofuels
Student: Caleb Talbot

Governor's Conference on Energy (2010, 2011, 2012)
Booth Exhibitor

Advisory Committee Member
Chris Bachmann, Associate Professor of Integrated Science and Technology

VA Statewide Wind Energy Symposium (2010 and 2012)
Participant

Virginia Biodiesel Conference (2010 and 2012)

Planning Committee Member
Chris Bachmann, Associate Professor of Integrated Science and Technology

Virginia Higher Education Energy Initiative Meeting (2010)

Keynote Speaker
Chris Bachmann, Associate Professor of Integrated Science and Technology

Project "Get Ready" (2010)
Participant

UVA ACORE Sustainable Ways to Community Prosperity (2011)
Participant

Suter Science Symposium (2011)

Presenter
Chris Bachmann, Associate Professor of Integrated Science and Technology

Virginia Rural Summit (2011)

Discussion Leader
Chris Bachmann, Associate Professor of Integrated Science and Technology

9th Annual International Conference on Heat Transfer, Fluid Dynamics, and Thermodynamics (2012)

Experimental Investigation of Hydrogen Enhanced Combustion in SI and CI Engines on Performance and Emissions
Students: D. Zammit, M. Farrugia, C. Bachmann, and R. Ghirlando (winner of "Best Paper")

Virginia Kid Wind Energy Challenge (2012)

Participant

Southern Bioenergy Conference (2012 and 2013)

Participant

VCU Energy and Sustainability Conference (2013)

Performance Evaluation of Water/Fuel Emulsion Device
Student: Joe Crosbie

Reducing the Cost of Biodiesel Production in the Shenandoah Valley
Students: Jon Hawkins and Jason McNamara

Novel Harvesting Strategies for Algae-based Biofuels
Student: Caleb Talbot

JMU Cycle Share
Student: Jonathan Blair

GSCI 101: The Energy Challenge
Students: Lindsay Nguyen, Daniel Fishman, Brandon Walraven, and James Will

Two-Phase Energy System
Students: Jack Cochran and Eric Leaman

Sustainability Assessment Software
Students: Sara Bethel, Emily Cummins, Paulina Hoang, Charles Ohrnberger, and Zurisadai Pena

Converting Waste Cooking Oil into Biodiesel
Students: Danny Vargas, Valerie Wade, Parker Helble, Nate Collins, and Rekan Mirawdaly

Food Day at JMU
Student: Laura Lorenz

Community Events - Hosted

25x'25 VA State Alliance Meeting (June 10, 2009)

During the summer of 2009, JMU convened a meeting of representatives from a wide range of interests who shared a common concern for promoting renewable energy and energy efficiency. With over 50 attendees, this was an early effort to form a state-level 25x'25 organization in the Commonwealth of Virginia. This meeting included much open-ended discussion, in addition to brief presentations by JMU faculty and administrators and a representative from the national 25x'25 organization.

Poultry Litter to Energy Discussion (February 28, 2012)

This discussion featured a panel of poultry litter-to-energy technology providers, as well as a panel with various stakeholders from the area. The goal of the event was to provide participants with a deeper understanding of the issues involved in utilizing poultry litter as an energy source.

Shenandoah Sustainability Summit (April 23, 2010)

Valley 25x'25 was the primary sponsor of the third sustainability summit held in Harrisonburg, Virginia. Building on the previous two summits, this event used a World Café format to facilitate open discussion for the more than 100 participants. Featuring discussions on a wide variety of topics of local interest, one notable and tangible product of the meeting was an effort to coordinate efforts among local sustainability organizations, which eventually coalesced as the Harrisonburg Rockingham Green Network.

Northend Greenway Discussion (May 17, 2012)

Valley 25x'25 convened a meeting between representatives of the Northend Greenway project in Harrisonburg and interested members of JMU's faculty and staff. The project focuses on creating a greenway for pedestrian and bicycle transportation and recreational use. As a consequence of the meeting, several JMU faculty and staff members have become actively involved with the Northend Greenway.

Community Events - Participated

Governor's Energy Project Recruitment Task Force (2009)

Special task force designated by Tim Kaine for the Virginia Economic Development Program (VEDP) to recruit energy companies to Virginia.

Rockingham County Fair (2009)

Alternative fuel vehicle display tent.

WVPT Kids' Book Festival (2011, 2012, 2013)

The WVPT Kids' Books Festival is an annual family event that celebrates the joy of reading. The event is filled with games, activities, entertainment, and various displays and demonstrations. Valley 25x'25 coordinated demonstration projects and displays from James Madison University's renewable and alternative energy programs.

Odyssey Day (2010 and 2012)

National Alternative Fuel Vehicle (AFV) Odyssey Day is a biennial event dedicated to promoting cleaner choices in transportation. The day is comprised of numerous green transportation-related events coordinated and hosted by NAFTC members, Clean Cities Coalitions, and others who believe in cleaner, more energy efficient forms of transportation. These local events take place on a designated date every other year throughout the U.S. and in Canada. Each local event site offers unique activities designed to educate attendees about cleaner transportation technologies and is tailored to the specific needs of the site's given audience. Examples of activities provided at the Valley 25x'25 sponsored event included: ride-and-drives, vehicle displays, workshops, demonstrations, panel discussions, and automotive lab tours.

JMU Bridges Program (2010)

The JMU Alternative Fuel Vehicle Lab provided demonstrations to students.

Virginia Insight (2010 and 2012)

Discussed alternative fuels on Virginia Public Radio.

USDA Forum on Biofuels (2010)

Invited as attendee and discussion leader.

Middle School Leadership Program at JMU (2011)

Hosted middle-school students from across the Commonwealth to encourage the next generation of students to engage with Science, Technology, Engineering, and Mathematics, so that they can develop the innovations needed to make clean, renewable energy solutions affordable and reliable.

August County Board of Supervisors and Planning Committee (2011)

Provided testimony about methane digester potential in Augusta County.

Rockingham County Board of Supervisors (2011)

Participated in a tour of Dominion's Mt. Storm wind and coal energy production facility, and facilitated discussions for expanding wind energy in Rockingham County.

Massanutten Rotary Club (2011)

Guest speaker.

Harrisonburg Rotary Club (2011)

Guest speaker.

Broadway 4-H Club (2012)

Guest speaker.

Massanutten Regional Libraries (2012)

Delivered "Awesome Inventors – and the importance of pursuing Science and Mathematics" lecture.

Harrisonburg Green Expo (2012)

Participated in an expo for sustainability-related businesses and organizations at Eastern Mennonite University. In addition to informing members of the public about energy efficiency and renewable energy options, it was an opportunity to network with others in the area who are committed to these issues.

Partnerships

Central Shenandoah Planning District Commission (CSPDC)

Valley 25x'25 partnered with the CSPDC on a collaborative grant proposal in response to a request for proposals through the Recovery Act: Energy Efficiency and Conservation Block Grants: Topic Area 2: The General Innovation Fund for Formula-Ineligible Local Governments and Formula-Ineligible Tribes. The proposal included three primary objectives: energy audits of public buildings and facilities; implementation of energy audit recommendations; and education, outreach, and training programs. This partnership also included collaboration on the successful implementation of the *Fields of Gold* initiative, which focuses on promoting agritourism in the Shenandoah Valley and is hosted by the CSPDC.

Firestone Complete Autocare

Valley 25x'25 has partnered with the local Firestone Complete Autocare store to offer multiple tire pressure awareness events for students, faculty, and members of the community. In addition to a free tire pressure check-up, participants received a short tutorial on tips to improve vehicle fuel economy. Ensuring tires are properly inflated is a cost-effective way to increase energy efficiency, as the EPA estimates a three percent decrease in fuel economy for every one psi of underinflation in all four tires.

Miller-Coors

Consulted with local brewery operations to discuss energy efficiency and renewable energy implementation options. This partnership is ongoing. Thermal imaging was used to quantify energy losses in un-insulated piping used in the brewing process. Economic analysis and overall cost-benefit comparison will be presented, and future plans include re-evaluating the thermodynamic model with new data taken after the installation of insulation around the piping is complete.

Wholesome Energy

Exhaust emissions from internal combustion engines have been gaining increased attention as a significant source of environmental pollution. Water-injection has been put forward as a means of reducing exhaust emissions, especially in diesel engines, but has required extensive engine modifications and comes with high installation costs. The purpose of this study was to evaluate the effectiveness of a novel device being marketed by Wholesome Energy of Edinburgh, VA, which claims to reduce emissions and fuel consumption by emulsifying water into vehicle fuel just prior to the injection system. The water-fuel emulsifying device was installed on a 2003 Mack CX600 tractor-trailer cab and tested on a Taylor water-brake dynomometer operating at 192 horsepower at 60 mph. Ten trials with water emulsion were compared to ten trials on straight diesel fuel. Particulate matter was reduced 50 percent (opacity and mass, $p<0.001$) and CO fell by 48 percent ($p<0.001$). These results indicate that significant environmental benefits could be achieved by using this device on diesel engines. Further tests using a gasoline-powered engine are currently underway to provide more conclusive results regarding fuel consumption and a full range of exhaust gas emissions, particularly nitrogen oxides (NOx). The device is easy to install and does not require significant engine modifications. It is also easily scalable. The device recently won an international competition against 60 entries from 16 countries because of its ability to reduce environmental pollution in marine vehicles, trucks, trains, construction equipment and any other application employing an internal combustion engine. The Virginia-based company will continue tests with JMU to investigate potential fuel savings and engine efficiency improvements.

The Wholesome Energy partnership expanded in 2012 to include modifying their water/fuel emulsion device for a different application: harvesting natural oils from algae in seawater. This novel approach to harvesting algae-oil without the energy-intensive dewatering step was first tried in August 2012 at JMU's Alternative Fuel Vehicle Lab. After several months of testing it was confirmed that the process was successful in purifying highly saturated lipids from aquatic species. The oil that was returned had comparable energy densities to diesel fuel. The partnership continues to investigate this novel algae-oil harvesting strategy and a potential patent disclosure is being pursued.

Shenandoah Agricultural Products

Valley 25x'25 initiated a partnership with Shenandoah Agricultural Products (Shen Ag) to help with their small-scale startup biodiesel operation. The goal of Shen. Ag was to provide a complete vegetable oil cycle that includes: supporting farmers in the growing of the feedstock crop, extracting the oil and protein meal, selling the oil to local restaurants, reclaiming the waste cooking oil, converting the waste oil into usable off-road biodiesel, and selling the finished bio-fuel back to local farmers. Valley 25x'25 supported basic scientific consultations about the process and provided funding to support an undergraduate summer internship at the Shen. Ag. facility. The student's task was to develop Standard Operating Procedures (SOP's) and safety documentation for the operation of the biodiesel reactor. In addition, the student suggested and implemented several in-house quality control measures. Stone Hill Construction (largest builder of agricultural facilities in the Shenandoah Valley) consulted to discuss on-farm solar and on-farm methane applications.

Virginia Clean Cities (VSBN)

A strategic partner of James Madison University, Virginia Clean Cities (VCC) assists the Commonwealth of Virginia improve air quality, increase U.S. national energy security, and promote economic, academic, and research opportunities in Virginia, primarily by promoting and facilitating increased use of alternative fuels and vehicles. The focus on transportation energy issues makes VCC a natural partner for Valley 25x'25.

Virginia Sustainable Building Network (VSBN)

Jeff Tang was one of two presenters to discuss the novel approach of the Harrisonburg Rockingham Green Network at the VSBN annual meeting in 2012. Approximately 50 attendees heard the presentation. As a supporter of building healthy, energy-efficient, environmentally friendly buildings, and sustainable communities, VSBN's goals align with those of Valley 25x'25.

Fibrowatt

Valley 25x'25 has periodically facilitated discussions between Fibrowatt (who specializes in the combustion of poultry litter to produce energy) and various local people and entities. Fibrowatt has been interested in locating a plant in the central Shenandoah Valley, and Valley 25x'25 has served as an impartial agent to share information about the various litter-to-energy approaches, including Fibrowatt's combustion system.

Legacy/Impact

Harrisonburg Rockingham Green Network (HRGN)

The Harrisonburg Rockingham Green Network was founded in 2011 as a network of sustainability-related organizations with the intention of better event coordination through a shared calendar (which is still operating at our website, www.hrgn.org) and a way to come together for political action on local issues of common interest to the various member organizations. Valley 25x'25 was not only a founding member, it also played an important role in organizing initial discussions before HRGN officially formed and in providing technical assistance once it was created. Jeff Tang has been the chair of HRGN since its creation.

Energy 101 Course

With an aim for moving beyond the theoretical into practice-focused education, Energy 101 is a course that introduces students with non-technical backgrounds to the basics of energy consumption in their everyday lives. A key component of the course is showing students how they can substantially reduce their energy usage without compromising their quality of life. The course is also unique in that it is completely student-led – it is a course for students taught by other students at JMU.

E-bike Libraries

Valley 25x'25 has been working to promote and locate funding for an electric-bike library for JMU students. The idea is that the hilly terrain on and around campus deters many would-be cyclists, and that e-bikes can be a great way to take some of the strain out of cycling on such a hilly campus. In addition, Valley 25x'25 has contributed to the purchase of four e-bikes for faculty and staff use so far, and a student project is currently studying attitudes and usage of e-bikes in a couple different application areas around campus.

Algae Research

The novel approach to harvesting algae-oil without the energy-intensive dewatering step continues at JMU's Alternative Fuel Vehicle Lab. Currently, eight undergraduate students are cultivating several algae strains for evaluation in the harvester. Two of the students are focusing on optimizing the process that was confirmed to yield highly saturated lipids with comparable energy densities to diesel fuel. One student is focusing on the design and implementation of a solvent recovery system to further improve the overall efficiency of the process. And a separate student is investigating the potential for the residual biomass derived in the process to be used as an animal feed. A potential patent disclosure is being pursued by JMU's Office of Technology Transfer.

Physics Follow-on Funding from NSF

After receiving initial seed funding from Valley 25x'25, Dr. Costel Constantin of JMU's Physics Department has continued to pursue his research on the thermoelectric properties of manganese oxide nanoparticles that could potentially be used for turning waste heat energy into electricity. He has since received NSF funding for this work.

Biochar Research

Professors in JMU's College of Integrated Science and Engineering have established a research program on biochar—fine-grained, highly porous charcoal made from a variety of biomass sources by a process known as pyrolysis—as a soil amendment for local farms. Valley 25x'25 provided funding for the necessary supplies to build the biochar units, and one such unit is sited at Joel Salatin's Polyface Farm in Swoope, VA. Faculty and students have since published and presented their findings.

NoNox Research

The water/fuel emulsification system that was evaluated with the financial and technical support of Valley 25x'25 is still under investigation. Preliminary testing showed a significant reduction in harmful emissions without a significant impact on fuel consumption. This year's current study is focusing on optimizing the water/fuel emulsion system to see if there is the potential to reduce fuel consumption in addition to reducing harmful exhaust emissions. The device was installed on a Wallenius Wilhelmson shipping vessel leaving port in Singapore to travel to the United States. The ship, a new generation Mark IV RoRo, is an 8-deck transport vessel capable of carrying 5310 cars. JMU undergraduate student Jackson Snarr joined the vessel in Washington State and sailed down the west coast, through the Panama Canal, and up the east coast stopping at ports along the way. Data from the ships central computer was matched with exhaust emission data from external monitors to account for variations in engine load, wind speed, and ocean currents, while tracking specific fuel consumption and exhaust gas generation. Data are still being analyzed; but preliminary results showed an average fuel savings of 1.6 percent. Additional testing in a 2003 Mack CX600 tractor-trailer is being conducted in a controlled environment using a chassis dynomometer. Executives from Wallenius Wilhelmson met with JMU faculty and expressed a desire to continue testing the device in their shipping fleet and expanding the discussion to include other exhaust gas scrubbing equipment currently under consideration.

Valley 25x'25 Website

Valley 25x'25 produced a high-quality website covering a wide range of topics related to energy efficiency and renewable energy in the Shenandoah Valley. Featuring blogs and news articles in addition to more static content, the website is a valuable resource for community members who want to know more about options for adopting a more sustainable way of living with respect to energy. One challenge for the site has been to maintain fresh content, especially with the expiration of funding and a change in jobs for the website's primary architect and content provider.

Conclusion

The Valley 25x'25 research and implementation effort produced a broad range of valuable experiences to increase awareness and promote the implementation of renewable energy strategies in pursuit of the national goal of achieving 25 percent renewable energy by the year 2025. It also yielded valuable insight into the challenges facing renewable energy implementation. It was found that many energy efficiency improvement strategies are economically viable and effective in reducing energy consumption over the long-term. However, current renewable energy strategies are challenging, as most are not cost-competitive compared to traditional energy resources. This is due (to a large extent) to a reduction in traditional energy costs over the past five years.

During the course of this project, significant developments in the oil and gas industry significantly increased proven reserves and dramatically altered price structures on a global scale. The success of hydraulic fracturing has greatly improved domestic energy security and resulted in excess production that continues to cause price reductions. These economic factors play a tremendous role in personal and business decisions regarding energy efficiency and renewable energy implementation. For example, gasoline prices in 2008 topped $4 per gallon with projections estimating further increases in coming years. This prompted a change in consumer demand and vehicles purchased, and was a common topic in the media. In 2013, gasoline prices dropped below $3 per gallon, resulting in a waning of public interest in alternative fuels. Natural gas prices peaked at $15 per MMBtu in 2008, compared to only $3.50 per MMBtu in 2013. This marked expansion in the natural gas industry has prompted many decision makers to reconsider previous renewable energy projects that seemed economically viable at the start of the Valley 25x'25 effort.

While this new abundant resource is highly valuable for energy security, it does little to resolve concerns over climate change. In 2013, the Intergovernmental Panel on Climate Change (IPCC) released its Fifth Assessment Report (AR5), which reported that the atmosphere and oceans have warmed unequivocally, and that sea levels have risen faster than previous models predicted. It concluded by stating that it is extremely likely that human influence has been the dominant factor for these measured changes, and that continued emissions will cause further changes in all components of the global climate system. In the meantime, China's economic growth continues at rates above seven percent, the International Energy Association predicts continued increases in energy consumption through 2030, and ExxonMobil predicts a 65 percent increase in energy consumption in developing nations by 2040. All of this will result in dramatic impacts on human populations if renewable energy and energy efficiency measures are not implemented. As noted by supporters of 25x'25—everyone is an environmentalist if it saves money, but not many are willing to take action if additional costs are incurred. Government assistance can help bridge the gap, but renewable energy cannot be permanently supported by government subsidies.

In conclusion, significant technical advances are needed to reduce the cost of renewable energy generation and distribution for both liquid fuels and electricity. Wide-spread implementation of clean, renewable energy will only happen in the United States if these energy options are cost-competitive compared to conventional systems and able to survive in a free market system. If these renewable energy options can be improved to provide the same level of performance as traditional fuels (reliable, consistent, and abundant delivery) without the consequent pollution and environmental impact and at the same cost, then it is very likely that the public will embrace these alternatives and widespread adoption and implementation will take place.

A TOOL TO ASSESS THE SUSTAINABILITY OF POULTRY LITTER TO ENERGY SYSTEMS

Final Report

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Executive Summary

In Virginia, over 535,000 tons of poultry litter are produced each year creating an enormous waste disposal problem which is gaining increasing environmental and regulatory notice. Current practices include repeated applications of poultry litter to pastures and hay meadows which can lead to accumulations of nitrogen and phosphorus in soil as well as elevated levels of one or both of these nutrients in surface runoff and subsurfacewater subsequently leading to eutrophication. The use of poultry litter as a fuel for energy generation has been proposed as a sustainable alternative to this form of disposal. Poultry litter to energy systems are touted as having better environmental performance. However, three dimensions of sustainability have traditionally been identified: economic, environmental, and social. It can thus be argued that while poultry litter to energy processes may appear to be a viable energy source with certain environmental benefits; this does not automatically imply that the overall system is sustainable. By considering the viewpoints of all stakeholders, the concept of sustainable development prescribes a focus on the "internalities" (efficiency, system performance, costs and direct environmental impacts) as well as the "externalities" (economic, social and indirect/cumulative environmental impacts) of developmental activities. Decisions on new practices and technologies are currently typically based on the perceived "greenness" of the method or technology itself, but the overall impact of all auxiliary operations as well the issues associated with risk transfer, socio-cultural acceptability and local micro-economics are typically not considered. There are currently no standards or metrics, for evaluating sustainable development practices. Likewise, there is no common guidance or framework to assure any standardization in the integration, of sustainable development practices. The framework for the development of a Sustainability Assessment Matrix (SAM) as a tool to guide the objective and systematized assessment of the economic, environmental and social impacts associated with current and proposed systems of poultry litter disposal was developed. This tool will allow for the comparison of overall systems as well as guide the decision of choices within subsystems by using indicators, arising from measured values and predicted, to summarize and condense the highly complex relationships to manageable and meaningful information. This work provides a basis for objective evaluation and comparison of the true impacts of new technologies and would be valuable to policy decision makers, energy producers, end users. Overall, the objective is to facilitate development in the direction of true and not merely perceived sustainability.

Introduction

Production of poultry and poultry products results in the generation of massive amounts of litter, a mixture of feces, feed, feathers and bedding materials such as straw, peanut or rice hulls, and wood shavings (Gupta et al., 1997) The poultry industry in the United States produces more than 11 million Mg of litter per year (Cabrera and Sims, 2000). Following removal from poultry production facilities, litter is commonly applied to pastures and hay meadows to increase forage production and quality (Sims and Wolf, 1994). Application rates from 4.5 to 11.2 Mg per ha per year are commonly used to supplement or replace normal annual fertilizer additions to pastures (Adams et al., 1994). Repeated applications of poultry litter can lead to accumulations of N and P in soil as well as elevated levels of one or both of these nutrients in surface runoff and subsurfacewater (McLeod and Hegg, 1984; Sharpley and Menzel, 1987; Kingery et al., 1994). High concentrations of N and P in runoff or subsurface water can contribute to accelerated eutrophication of water bodies, impairing their use and potentially leading to fish mortality and growth of algae (Lemunyon and Gilbert, 1993). Elevated concentrations of N and P in surface water and eutrophication of water bodies have been found in areas with high levels of confined poultry and other animal production (Daniel et al., 1998). It is estimated that 50% of the litter produced from areas with high concentrations of poultry production facilities cannot be applied to agroecosystems in these same areas due to environmental or economical constraints (Wimberly, 2002). Poultry litter has also been used as a feed source for cattle, sheep and goats due to its high crude protein, mineral and energy content. In addition to nutritional benefits, poultry litter reduces production costs. For example, feed costs were lower for cows fed diets supplemented with poultry manure than for those fed diets supplemented with soybean meal (Jackson et al., 2006). The land disposal of waste from the poultry industry and subsequent environmental implications has stimulated interest into cleaner and more useful disposal options. Aerobic composting has been shown to be successful and the end material can be sold commercially as an organic fertiliser. The main disadvantage is the loss of nitrogen resulting in a material of less commercial and practical value. This nitrogen loss contributes to an undesirable volatilisation of ammonia to the atmosphere or nitrate to water bodies. Anaerobic digestion of poultry litter has also been investigated as a disposal option.

There have been studies reporting the feasibility of using poultry litter as an alternative, natural fuel source for power generation (Davalos et al., 2002). While the calorific value of poultry litter decreases with increasing moisture content, air dried samples have been reported as having a typical value of 13.5 GJ/ton, which is about half that of coal. The use of poultry litter as a fuel has been touted as having the added benefit that only trace concentrations of elements like nitrogen or sulphur are present in the gaseous products of combustion thus leading to a dilution of emissions of pollutants such as NO_x and SO_2.

Human development practices consume raw materials and energy while creating associated environmental, social and economic impacts. Poultry litter to energy processes may appear to be a viable energy source with certain environmental benefits; this does not automatically imply that the overall system is sustainable. While sustainability may not mean the same things to all groups, it is generally agreed that ecosystem well-being and human well-being are criteria that must be improved to approach sustainable development (Singh et al., 2009). By considering the viewpoints of all stakeholders, the concept of sustainable development prescribes a focus on the "internalities" (efficiency, system performance, costs and direct environmental impacts) as well as the "externalities" (economic, social and indirect/cumulative environmental impacts) of developmental activities. For example, while reducing carbon emissions and security of energy supply are headline issues at the national level, local communities are likely to consider job creation, income improvement, the local environment and regional development as at least equally important in leading to support for or opposition to any new energy plant (Domac et al., 2005). Decisions on new practices and technologies are currently typically based on the perceived "greenness" of the method or technology itself, but the overall impact of all auxiliary operations as well the issues associated with risk transfer, socio-cultural acceptability and local micro-economics are typically not considered. Decisions taken to actualize a sustainability objective may result in domino effect consequences that are ultimately contra-sustainability and might even nullify any achievements made upstream. Acknowledgment of the interdependence of so many sub-systems and attributes (i.e. technologies, costs, risks, social acceptance, environment and legal frameworks) makes the development of a simplified tool to guide the implementation of new technologies and practices and assessment of how truly effective and sustainable they are, necessary and very challenging.

In Virginia, over 535,000 tons of poultry litter are produced each year creating an enormous waste disposal problem which is gaining increasing environmental and regulatory notice. Consequently, there are many projects, both in the USA and European countries, researching the environmental effects and economic benefits of poultry litter combustion for power generation. This research project contends that with the mining of patterns in the various technologies and processes for poultry litter combustion for energy production, we can begin to develop the framework by which we can identify relevant and effective metrics for assessing the sustainability of these technologies and processes. The framework for the development of an assessment tool to be used in the comparative analysis of the sustainability of the various alternatives of poultry litter disposal particularly poultry litter to energy technologies is presented. The scope and detail of any framework directly relies on the proper identification of the domain and system boundaries. These boundaries need to be inclusive enough to accurately portray how truly sustainable the approach is, yet not burden the analysis with extraneous information.

Scope of work

The initial scope of work was modified to reflect the approved grant support. The new tasks proposed with the scope were:

1. Establish the decision context
    a. identify primary stakeholders
    b. identify the socio-technical boundaries of the system
2. Identify current and proposed options for poultry litter disposal
    a. Develop a generic life cycle architecture identifying shared or comparable subsystems
3. Identify relevant and measurable indicators to be evaluated
    a. Develop models for evaluating/assessing identified indicators.
    b. Develop a normalization, weighting and scoring system for indicators

Tasks 1-3 of the original task schedule were proposed to be completed over a month of summer work. Task 3 was completed while Tasks 1 and 2 were partially completed due to constrains resulting from difficulty in acquiring information from key stakeholders. Fibrowatt LLC was identified as a significant stakeholder in poultry-litter to energy technologies in the Shenandoah

Valley. However, multiple efforts to obtain information or audience with a representative proved futile. Consequently, the research focused on developing the framework for future assessments.

Methodology

Three dimensions of sustainability have traditionally been identified: economic, environmental, and social. More recent works have also included an institutional dimension to ensure compatibility with local culture, moral issues and ethics through consensus (Thornton et al., 2007). Other dimensions are often proposed when considering standards or guiding principles of various included professions and specializations. (Pawlowski, 2007). The predominant approach so far has been to develop and institute paradigms that generally only consider individual dimensions of sustainability. Thornton et al. (2007) noted that the dimensions of sustainability will always compete with each other to some extent and for each benefit there will be a "disbenefit", thus true sustainability cannot be achieved. An optimum level can however be realized by treating systems as organic wholes and implementing flexibilities and thresholds within sub-systems that allow for tradeoffs that results in a resilient, adaptable and consequently transformable system. Figure 1 shows the classical model of sustainability that allocates equal treatment to all three dimensions. However, this model neglects the contextual differences that across various communities dealing with what may appear to be the same issues. Rather, a more realistic model allows decisions makers to assign weights to the dimensions depending on the relevant concerns.

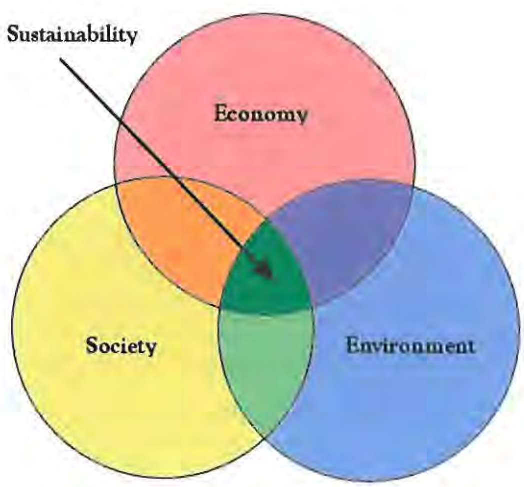

Figure 1. The triple-bottom line model of sustainability

The framework for the development of a Sustainability Assessment Matrix (SAM) as a tool to guide the objective and systematized assessment of the economic, environmental and social impacts associated with current and proposed systems was developed. This tool will allow for the comparison of overall systems as well as guide the decision of choices within subsystems. Overall, the objective is to facilitate development in the direction of true and not merely perceived sustainability.

At the core of any effort to develop a framework or tool to assess sustainability initiatives are indicators, arising from measured values, used to summarize and condense the highly complex relationships to manageable and meaningful information (Godfrey and Todd, 2001). Generally, economists are inclined to monetary yardsticks while scientists tend to use physical indicators to measure sustainability. However, indicators themselves are meaningless without well defined reference values (Lancker and Nijkamp, 2000) and comparability across time and space. This, considering the fact that sustainability as a concept is not spatially or temporally bound, means that the most sustainable approach to any given problem might sometimes not be the most optimal from the traditional point of view. As a matter of fact, depending of the system boundaries, efficiency may sometimes have to be sacrificed (Singh et al., 2009).

What is of interest is not whether the process leads to a decision that satisfies the wishes of any sector group of stakeholders, because different groups have different concerns and objectives; the interest lies in whether the process is able to integrate and reconcile different objectives.

Work Done and Results

The limited scope of this project was aimed at developing the guidelines for an assessment tool that is transparent in the input of data, and assumptions and that helps stakeholders to make balanced decisions rather than perform the assessment per se.

Identified stakeholders in poultry litter to energy systems include

- poultry producers
- energy project developers
- technology providers
- utilities suppliers

- end-users
- the financial community
- policy makers, regulators and planners
- members of communities directly and indirectly affected.

A critical part of the work done was the identification of measurable sets of indicators that could adequately represent measures of the sustainability of existing and proposed systems by capturing the concerns of relevant stakeholders. Not all indicators are measurable and we are not aware of any reference that guides the choice of indicators rather, a heuristic approach should be taken in the choice of relevant and applicable indicators. Necessary attributes of selected indicators include

- Relevance: How relevant is the criterion to the concept of sustainable poultry litter disposal? Does its assessment contribute to a better understanding of the sustainability of the system?
- Practicality: Are there existing scales and/or measurement units? Are there measurable threshold values? How easily can data be obtained? Is measuring the indicator cost, time and/or resource effective?
- Reliability: How reliable is the result of assessing the criterion? Is there a high uncertainty attached to the criterion? Are results reproducible? How easily can consensus be achieved?

A list of generic indicators that have been identified as germane to poultry litter to energy systems include:

Social Indicators

- Land availability for other human activities
- Community Participation (inclusion in decision making)
- Cultural Acceptability
- Working Conditions
- Standard of living
- Property rights

- Visual impacts
- Noise impacts
- Diversity
- Employment
- Direct and indirect casualty rates

Economic Indicators

- Employment generation
- Money spent on local business
- Average salary and wages
- Process costs
- Energy costs
- Tax revenue

Environmental Indicators

- Energy Balance
- Natural resource efficiency
- Ecosystems impact
- Land use
- Soil contamination
- Water consumption
- Water quality
- Waste management
- Greenhouse gas balance
- Atmospheric emissions

These indicators are broadly defined to serve the purpose of allowing for available metrics and data to be used in the assessment. Several operational requirements/constrains have also been identified. Namely:

- Minimize environmental impact
- Minimize risk
- Minimize life cycle costs

- Maximize social acceptance
- Maximize economic benefits

Recognising that assessment of impacts must account for the whole product or process life cycle, a gate to grave life-cycle approach is appropriate to cover all the stages from poultry litter collection, through pretreatment, storage, transportation, processing and disposal. Figure 2 shows a general schematic of a typical poultry litter-energy process.

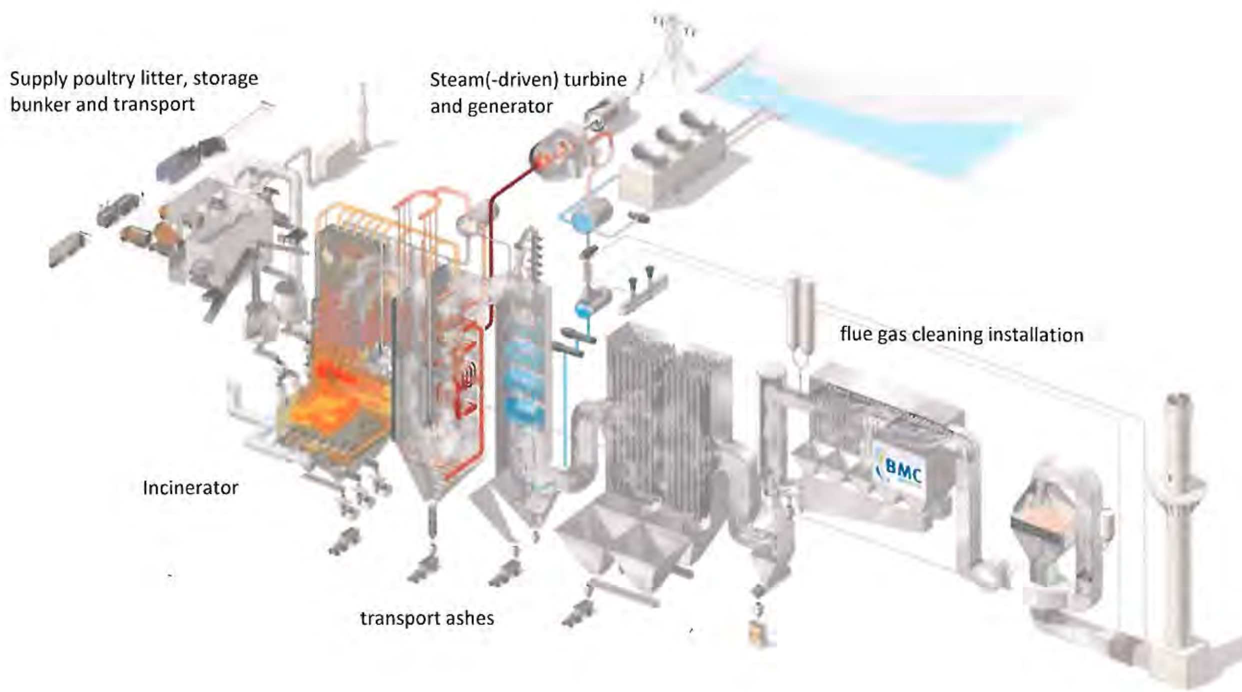

Figure 2. Schematic of a typical poultry litter to energy process (from BMC Moerdijk's Process http://www.bmcmoerdijk.nl/upload/cms/0/Procestekening29.pdf)

This framework also accounts for the energy systems that would be displaced by the energy output from the the poultry litter system accounting for avoided impacts as well as direct and indirect impacts. Data can be mined from available information in the literature (i.e., case studies, technology description, etc.). Databases like Ecoinvent and EIO-LCA (Economic Input-Output Life Cycle Assessment), and existing tools that feature balances of mass and energy flows such as SimaPro can be used to assess the overall impacts of the activities being evaluated.

Our methodology starts with the premise that sustainability is a function of environmental, economic and social variables.

Thus

$$S = f(x_e, x_\$, x_s)$$

Where

S = Sustainability factor defined as a measure of the overall sustainability of the system.

x_e = composite environmental indicator defined as a measure of the environmental impact

$x_\$$ = composite economic indicator defined as a measure of the economic impact

x_s = composite social indicator defined as a measure of the social impact

The assessment matrix comprises three main columns representing all three dimensions and three rows *a*, *b*, and *c* representing the stages of the life cycle of the process according to a predefined scope. The matrix is populated by composite indicator values for each dimension in each of the three life cycle stages. This format allows for the identification of specific areas of concern and possible improvements.

Table 1. Sustainability assessment matrix

	Environmental	Economic	Social
a; Poultry litter collection, transport and storage	x_{ea}	$x_{\$a}$	x_{sa}
b; Incineration and Energy generation	x_{eb}	$x_{\$b}$	x_{sb}
c; Residue transport and disposal	x_{ec}	$x_{\$c}$	x_{sc}

Each composite indicator is the weighted sum of normalized values of multiple indicators of that dimension of sustainability.

$$x_e = f(x_{e1}, x_{e2}, \dots \dots . . x_{eN})$$

$$x_\$ = f(x_{\$1}, x_{\$2}, \dots \dots . . x_{\$N})$$

$$x_s = f(x_{s1}, x_{s2}, \dots \dots . . x_{sN})$$

Where

x_{ei}, $x_{\$i}$ and x_{si} are values of the relevant and chosen environmental, economic and social indicators respectively.

Various methods have been proposed for computing composite indicators (Singh et al.). We have chosen the rescaled values method for normalization in addition to the simple additive weighting method for weighted values such that the composite indicator value for each dimension of sustainable for each of the three stages of the life cycle of the process can be calculated. For example composite environmental indicator for the poultry litter collection, transport and storage phase of the process is given by

$$x_{ea} = \frac{\sum_1^N w_i \left(\frac{x_{ei} - x_{em}}{x_{eM} - x_{em}}\right)}{\sum_1^N w_i}$$

Where

x_{ei} in this equation, represent the individual values of the environmental indicators for the litter collection, transport and storage phase

x_{em} is the minimum (low threshold value) of that environmental indicator

x_{eM}, *is* the maximum (high threshold) values of that environmental indicator

w_i is the weight assigned to each indicator. This allows for consideration and prioritization of contextual realities.

This equation is adjusted accordingly for indicators for which low values are desirable.

Thus

$$x_{sb} = \frac{\sum_1^N w_i \left(\frac{x_{si} - x_{sm}}{x_{sM} - x_{sm}}\right)}{\sum_1^N w_i}$$

would be the equation for the composite social indicator for incineration and energy generation life cycle stage.

Values obtained for all indicators under each category can then be synthesized into one single score value of sustainability. This will be one of the main focuses of future research.

Research Contributions and Conclusions

A fundamental driver of this project is that there are currently no standards or metrics, for sustainable development practices. Likewise, there is no common guidance or framework to assure any standardization in the integration, architecture, and development of sustainable development practices. The plan for a basic framework for assessing the sustainability of a poultry litter to energy system using a sustainability assessment matrix was developed. This work provides a basis for objective evaluation and comparison of the true impacts of new technologies and would be valuable to policy decision makers, energy producers, end users. Inability to obtain relevant data and information from identified stakeholders within the project time constrained the completion of the proposed scope. However, the work completed can serve as the foundation for future research work.

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Final Report for

Materials for Solar Hydrogen Production and Next-Generation Photovoltaic Cells

a project funded by the Institute for Energy and Environmental Research (IEER)

at James Madison University (JMU)

by

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Materials for Solar Hydrogen Production and Next-Generation Photovoltaic Cells

Project Summary

Widespread, large-scale use of solar energy requires methods to efficiently convert light energy into electrical energy. Further, methods for converting captured solar energy into a fuel, such as hydrogen, for use when sunlight is not available and/or for transportation applications are needed. Hydrogen gas can be obtained through photoelectrolysis by illuminating photosensitive semiconductor materials immersed in an electrolyte solution. To date, suitable, low-cost, chemically stable materials for photoelectrolysis have not been developed. However, there is significant interest in doped $BiVO_4$ and CZTS thin films for photoelectrolysis and next-generation PV cells.

Based on substantial theoretical work, National Renewable Energy Laboratory (NREL) researchers recently concluded that the addition of dopants such as Ca, Na, and K to $BiVO_4$ thin films should produce excellent p-type semiconductor properties and conductivity. This work also concluded that Mo and W doping of $BiVO_4$ should result in excellent n-type conductivity. Such enhanced electrical conductivity is expected to lead to enhanced hydrogen production efficiencies in photoelectrochemical (PEC) cells. Additionally, if $BiVO_4$ with sufficiently high p-type and n-type conductivities can be prepared, this material may also be used as tunnel junction material for next-generation, multi-junction photovoltaic (PV) cells.

This investigation examined the effects of specific dopants on the electrical and PEC water splitting performance of $BiVO_4$. Doped thin-film $BiVO_4$ samples were prepared from a variety of different chemical precursors using a spray pyrolysis technique, a relatively low-cost technique that could be scaled for high volume production, followed by annealing. The morphology, chemical composition, and crystallinity of the prepared BiVO4 films were analyzed using scanning electron microscopy, UV/VIS spectroscopy, and x-ray diffractometry. Electrical conductivity and PEC performance tests were also performed on the samples.

Results of this investigation demonstrated that doped $BiVO_4$ thin-films can be created using the spray pyrolysis deposition technique. Chemical precursors and additives greatly influenced the morphology of the produced thin-films; however, the morphology of the thin films was not significantly impacted by the inclusion of dopants. Films deposited from precursors containing ethylene glycol and EDTA resulted in thinner, smoother films which provided higher optical transmittance for wavelengths greater than 500 nm, a characteristic desirable for next-generation PV cell tunnel junction materials. Consistent with the NREL theoretical predictions, the addition of Mo and W dopants resulted in n-type behavior while the addition of Ca dopants indicated p-type behavior when tested in the PEC cell. W doped samples annealed in 3% H_2 generated the highest photocurrent densities during PEC testing. However, high material conductivity was not achieved in any of the samples produced.

Future work will focus on increasing the conductivity of the $BiVO_4$ samples through the selection of precursor chemicals and dopants. Additionally, work on CTZS thin film materials is proposed.

Materials for Solar Hydrogen Production and Next-Generation Photovoltaic Cells

A. Objectives

The objectives of our investigation of $BiVO_4$ are to determine the effects of specific added dopants (Sr, Ca, Na, K, Mo, and W) on the electrical properties and the photoelectrochemical (PEC) water splitting performance of this material. Based upon substantial theoretical work, NREL researchers have recently concluded that Sr, Ca, Na, and K addition to $BiVO_4$ should produce excellent p-type conductivity.[1-2] Additionally, they concluded that Mo and W should produce excellent n-type conductivity. Such enhanced electrical conductivity is expected to lead to enhanced hydrogen production in a PEC cell. In addition, if $BiVO_4$ with sufficiently high p-type and n-type conductivities (i.e., sufficiently *low* p-type and n-type *resistivities*) can be prepared, this material may also be applicable to next-generation tandem photovoltaic (PV) cells. Our activities were centered on a study of the effects of dopants on the performance of $BiVO_4$ for PEC water splitting while also testing the theoretical predictions of the NREL group.

B. Synthesis and Morphology of $BiVO_4$ Thin Films

Our materials synthesis activities during the performance period were focused on the preparation of thin films of undoped and doped $BiVO_4$ by the spray pyrolysis technique.[3-4] Prior to the start of this project we deposited thin films of SnO_2 and WO_3 by spray pyrolysis and we did some preliminary work on the deposition of $BiVO_4$. During the spring of 2011, Brandon Lancaster, who is currently a junior Engineering major, worked with us on the automation of the injector nozzle motion on the spray pyrolysis deposition system. We completed the design work and the required new parts were fabricated in the JMU machine shop prior to the start of this project. Two students worked with us during the performance period. Brandon Journell, who is currently a senior Engineering major, was paid by this grant and he is continuing to work on this project as part of a team of four students who are designing an improved solar hydrogen materials testing system for their engineering design project. Milan Patel, a May 2011 graduate of New River Community College, worked with us as a participant in the JMU Materials Science Research Experiences for Undergraduates (REU) Program and he was paid by that program, funded by the US Department of Defense ASSURE program in partnership with the National Science Foundation REU Grant – DMR-0851367.

At the start of this project we completed the assembly of our improved spray pyrolysis deposition system. The components of this system are shown in Figure 1. In spray pyrolysis, the starting material is a precursor solution that contains dissolved compounds of the required chemical elements. For example, to deposit thin films of $BiVO_4$ the precursor solution consists of dissolved bismuth and vanadium compounds. Figure 1(a) is a photograph of the nebulizer, in which an ultrasonic transducer is used to create a fog of the precursor solution. This mist is transported by a flow of air through a tube to the reactor, shown in Figure 1(b). Inside the reactor, the precursor mist is directed through a stainless steel nozzle onto a heated substrate. The substrates that we use are standard soda-lime glass microscope slides, silica (SiO_2) slides, and glass slides that are coated with a transparent conducting film of indium tin oxide (ITO). Chemical reactions that yield $BiVO_4$ occur on the substrate surface. A portion of the new mechanism that translates the nozzle back and forth over the substrate surface is visible on top of the reactor in Figure 1(b). This feature makes it possible for us to deposit films with improved thickness uniformity. The deposition temperature is typically 390 to 430°C and the deposition time is typically 8 to 25 minutes. Deposited films range in thickness from 200 nm to 4600 nm.

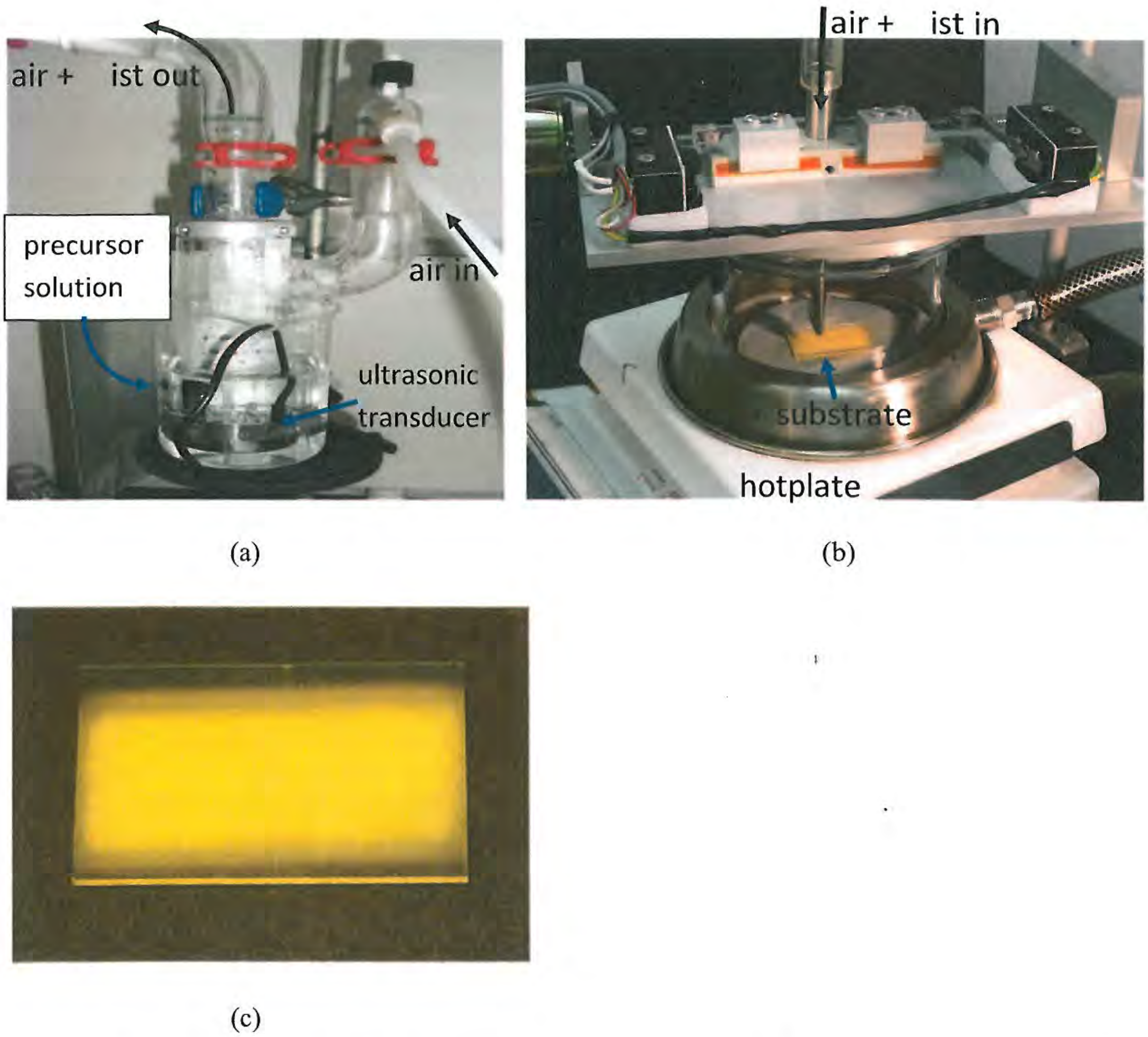


Figure 1. Spray pyrolysis thin film deposition system, showing: (a) nebulizer used to create a fog of the precursor solution, and (b) reactor in which the precursor mist, transported by air, impinges on a heated substrate. The nozzle that delivers the precursor is continuously translated left and right over the substrate. (c) A typical $BiVO_4$ film deposited on a glass microscope slide is shown. The slide is 1" x 1.5".

The $BiVO_4$ film morphology is important for solar hydrogen applications because microscopically porous films will have a larger surface area in contact with water in a photoelectrochemical (PEC) water splitting cell. This is favorable for charge transfer across the solid-liquid interface, which is required for the oxidation and reduction reactions associated with water splitting. A potentially detrimental effect of film porosity is that charge transport through the film can be hindered by the longer, more circuitous path than that in a dense film. If $BiVO_4$ films are to be useful in next generation tandem PV cells, in most cases the coatings will need to be dense and conformal. Given these considerations, we want to develop the capability to deposit $BiVO_4$ films with varied morphologies. The morphology of layers deposited by spray pyrolysis depends on which bismuth and vanadium compounds are used to prepare the precursor solution. Chemical additives can also affect the morphology. A further reason to investigate several precursor compounds is to determine if any might produce films with improved electrical properties, specifically high conductivity (low resistivity).

Bismuth nitrate ($Bi(NO_3)_3 \cdot 5H_2O$) was used as the bismuth source in all the precursor solutions prepared to this point. Three different vanadium sources have been investigated so far: ammonium vanadium oxide[5] (NH_4VO_3), vanadium oxysulfate[6] ($VOSO_4 \cdot xH_2O$), and vanadium(III) chloride (VCl_3). We have deposited undoped $BiVO_4$ films and films doped with molybdenum (Mo), tungsten (W) and calcium (Ca) in experiments intended to determine whether doping can enhance the PEC water splitting performance and the electrical conductivity, as predicted by NREL researchers.[1-2] In order to deposit doped films, the desired dopant was added to the precursor solution in a concentration of from 1% to 7% of the total Bi + V concentration. Two precursor additives have been investigated in order to observe their effects on film morphology: ethylenediaminetetraacetic acid[5] (EDTA) and ethylene glycol. Film thicknesses were measured with a surface profiler and film microstructures were examined with an optical microscope and a scanning electron microscope (SEM).

SEM micrographs of $BiVO_4$ films deposited from four different precursor solutions, undoped and doped, with and without additives, are presented in Figure 2. We have observed that adding ethylene glycol or EDTA to the precursor solution tends to result in smoother films and a substantially slower deposition rate. Films deposited from $VOSO_4 \cdot xH_2O$ tend to exhibit a micro-porous structure with large surface area. In this case the apparent deposition rate is large; however, much of the apparent film volume consists of "empty space". Dopant additions of up to 7% do not appear to affect the film morphology. Films deposited from VCl_3 have not yet been examined with the SEM.

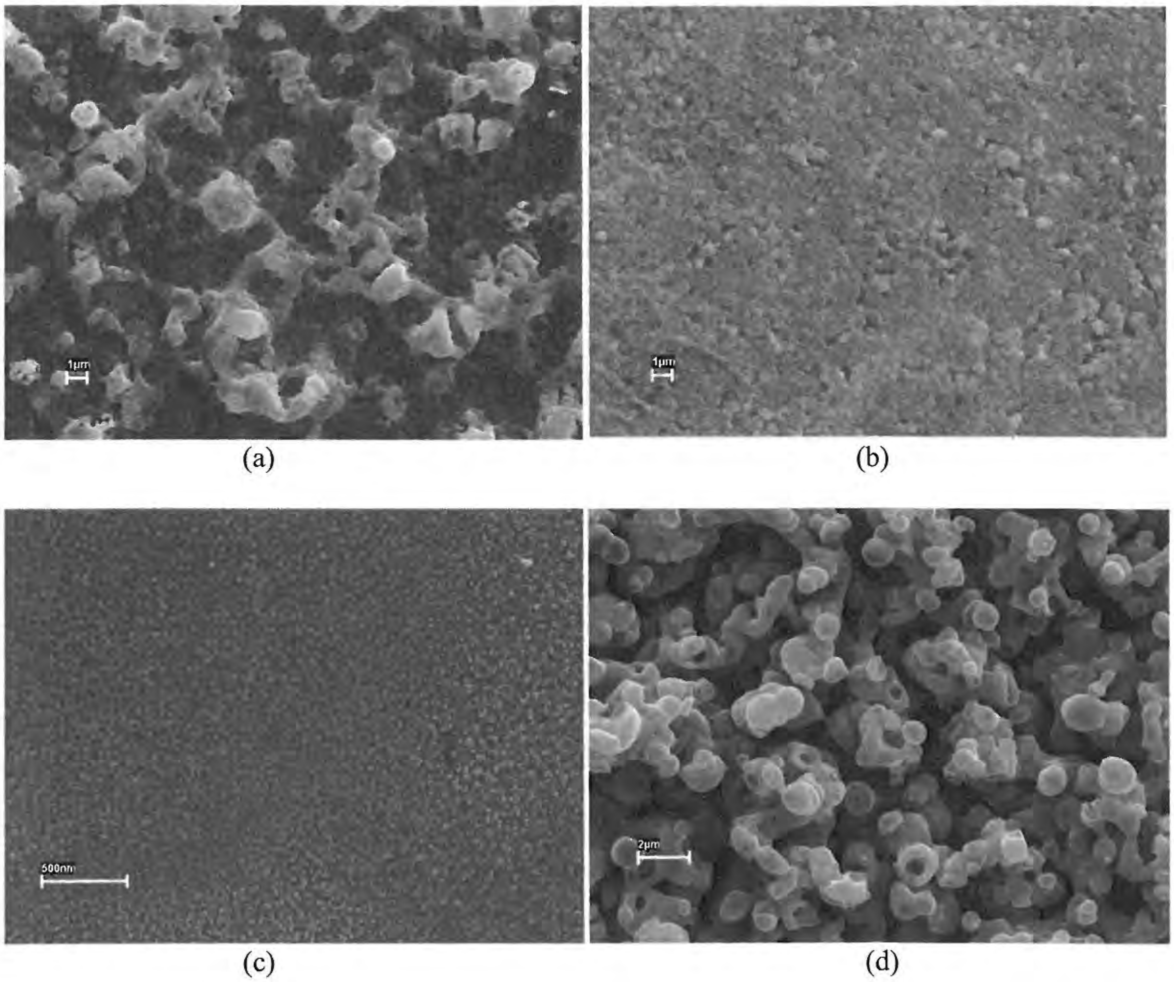


Figure 2. SEM micrographs of $BiVO_4$ films deposited from four different precursor solutions. $Bi(NO_3)_3 \cdot 5H_2O$ was used as the bismuth source in all cases. The vanadium sources, dopants, additives, deposition times (t), and film thicknesses (d) are as follows : (a) NH_4VO_3, 3% Mo doping, t=18min., d=1300nm, (b) NH_4VO_3, 3% W doping, ethylene glycol added, t=25min., d=200nm, (c) NH_4VO_3, undoped, EDTA added, t=8min., d=220nm, (d) $VOSO_4 \cdot xH_2O$, undoped, t=25min., d=4600nm.

C. X-Ray Diffraction and Annealing of $BiVO_4$ Thin Films

$BiVO_4$ films deposited from two different precursor solutions were characterized by x-ray diffraction. Dr. Barbara Reisner of the JMU Department of Chemistry assisted with these measurements. The x-ray diffraction spectrum from a film deposited from $Bi(NO_3)_3 \cdot 5H_2O$ and $VOSO_4 \cdot xH_2O$ at 390°C is shown in Figure 3. The peaks in this spectrum have not been definitively identified, but they result from multiple compounds of Bi, V, O, and perhaps S. Annealing the film in air for three hours at 500°C converts it into the desired $BiVO_4$ phase, whose spectrum is also shown in Figure 3.

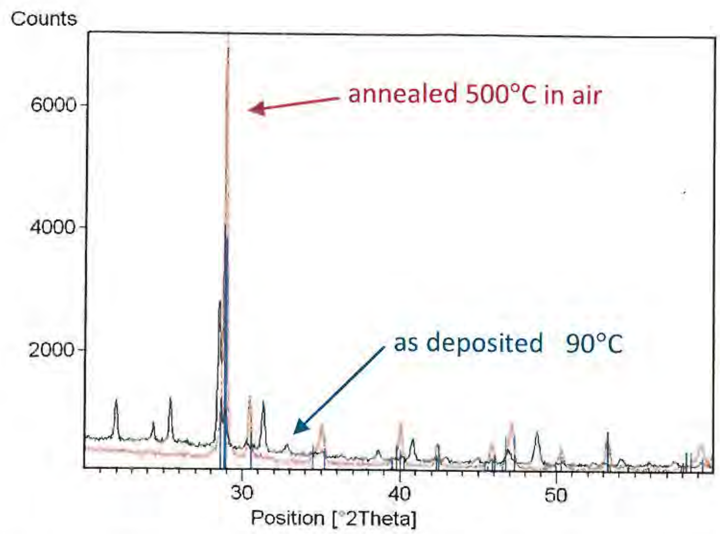
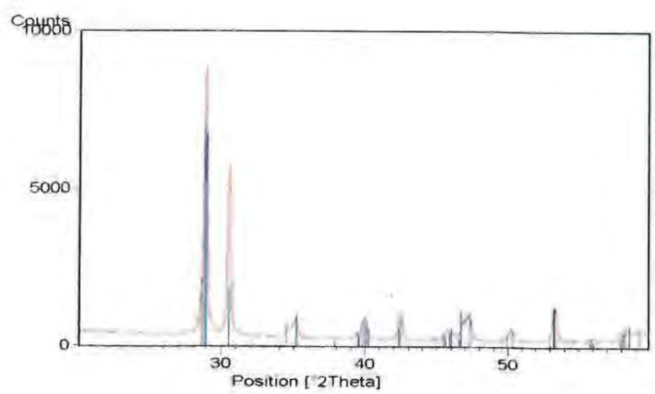


Figure 3. X-ray diffraction spectra before and after annealing for a film deposited from $Bi(NO_3)_3 \cdot 5H_2O$ and $VOSO_4 \cdot xH_2O$.

The x-ray diffraction spectrum from a $BiVO_4$ film deposited at 425°C from $Bi(NO_3)_3 \cdot 5H_2O$ and NH_4VO_3, with added EDTA, and annealed in air for three hours at 500°C is shown in Figure 4(a). The peaks in the spectrum correspond well with those expected for the desired $BiVO_4$ phase, which are identified by the vertical blue lines in the figure. Figure 4(b) shows a portion of the spectrum near $2\theta=30°$ before and after annealing the film at 500°C. It is evident that annealing increases the height of the peaks while decreasing their width. This indicates that the crystallinity of the $BiVO_4$ film is improved by annealing in air.



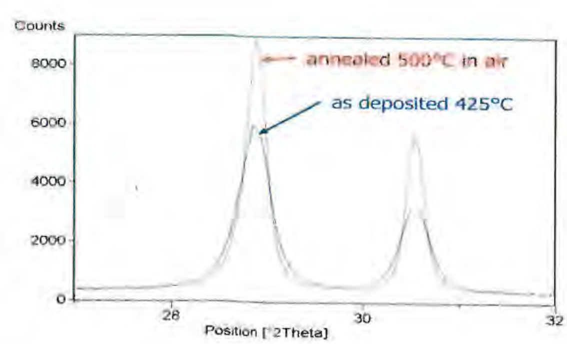


Figure 4. (a) X-ray diffraction spectrum after annealing for a film deposited from $Bi(NO_3)_3 \cdot 5H_2O$ and NH_4VO_3 with added EDTA. (b) A portion of the spectrum showing the effect of annealing.

D. Optical Properties of $BiVO_4$ Thin Films

The optical properties of $BiVO_4$ films deposited on glass were assessed by measuring their light transmission characteristics with a UV/visible spectrometer. Typical transmittance spectra are shown in Figure 5. All three films were deposited from $Bi(NO_3)_3 \cdot 5H_2O$ and NH_4VO_3. In addition, film #054-Mo EG was 3% Mo doped and ethylene glycol was added to the precursor solution. Film #056-W EG was 3% W doped and ethylene glycol was added. The precursor for film #049 had no dopants or additives, so that film was thicker and had a rougher morphology, resulting in more light scattering and less light transmission. Films deposited from precursors containing ethylene glycol or EDTA are thinner and smoother and as a result they have higher transmittance for wavelengths above 500nm. The sharp absorption edge near 500nm, with shorter wavelength light being absorbed, is consistent with an energy gap of 2.4 to 2.5eV, as expected for $BiVO_4$.[1-2]

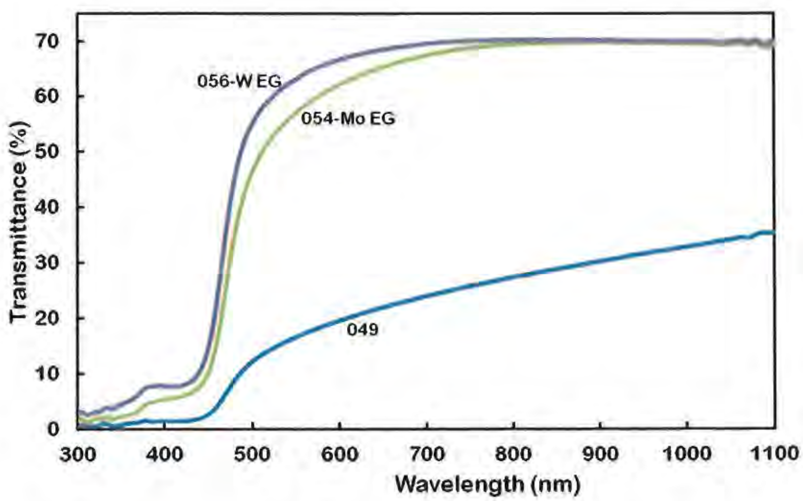


Figure 5. UV/visible transmittance spectra of $BiVO_4$ films.

E. Electrical Conductivity of $BiVO_4$ Thin Films

After reviewing the theoretical work of NREL researchers, we expected that producing conductive $BiVO_4$ thin films would be reasonably straightforward, though we also recognized that optimization of the electrical properties would take substantially more effort. We have found that achieving even minimal conductivity is much more challenging than anticipated. As described in section B, we have produced $BiVO_4$ films from several vanadium compounds, including ammonium vanadium oxide[5] (NH_4VO_3), vanadium oxysulfate[6] ($VOSO_4 \cdot xH_2O$), and vanadium(III) chloride (VCl_3). We have so far only used bismuth nitrate ($Bi(NO_3)_3 \cdot 5H_2O$) as the bismuth source. We have deposited undoped films and films doped with molybdenum (Mo), tungsten (W) and calcium (Ca). The NREL researchers predict that Mo and W should produce excellent n-type conductivity and that Ca should produce excellent p-type conductivity.[1-2] All of our undoped and doped $BiVO_4$ films prepared from NH_4VO_3 and $VOSO_4 \cdot xH_2O$ have unmeasurably high electrical resistance, i.e., greater than $1G\Omega$ as determined from attempted two-wire measurements. This indicates that the material has near zero electrical conductivity. In trying to understand the low conductivity we must recognize that the material is polycrystalline and that perhaps poor electrical contact between adjacent grains is at least partly responsible (grains are most evident in

Figure 2(c)). High grain boundary resistance could possibly result from insulating compounds formed along those boundaries from the precursor chemicals during the spray pyrolysis process. Our hope was that the high temperature (500°C) annealing in air that improves the crystallinity of the films (see Figures 3 and 4) would also oxidize, volatilize, and hence remove any unwanted grain boundary compounds. We also tried annealing films in a reducing atmosphere of 3% hydrogen (balance nitrogen) at 375°, but the films still had unmeasurably high electrical resistance.

In an effort to reduce the likelihood of forming undesired insulating compounds at grain boundaries, we are trying to develop a "cleaner" $BiVO_4$ deposition chemistry. Our first step in this direction is to prepare films from $Bi(NO_3)_3 \cdot 5H_2O$ and VCl_3, a simpler vanadium source. This work has produced encouraging results in that we have deposited several $BiVO_4$ films with resistances between 200MΩ and 800MΩ, which while high is at least measureable. The corresponding $BiVO_4$ resistivities are on the order of 10^4 Ω-cm. We would like to develop processes to produce both n-type and p-type films with resistivities well below 1 Ω-cm. Our next step is to try to deposit films from a precursor solution in which both the bismuth and vanadium compounds are chlorides: $BiCl_3$ and VCl_3. We have not found any literature reports on the production of $BiVO_4$ from these compounds, however, other conducting oxide films, such as SnO_2, In_2O_3, ZnO, and mixtures of these compounds, have been deposited by the spray pyrolysis of chloride precursors[3-4]. In addition to spray pyrolysis, there are literature reports on the preparation of these conducting oxides by printing the chlorides on a substrate at low temperature and then heating the chloride film so that it reacts with oxygen, yielding the desired oxide film[7]. This gives us another closely related approach that may lead to conducting $BiVO_4$ films. This is worthy of investigation because spray pyrolysis and printing followed by pyrolysis are both low cost film manufacturing techniques capable of being scaled up to coat large areas since they are carried out at atmospheric pressure (no expensive vacuum processing is required). Low manufacturing cost is essential to make solar hydrogen and photovoltaic electricity practical.

F. Photoelectrochemical (PEC) Performance of $BiVO_4$ Thin Films

The photoelectrochemical properties of the doped $BiVO_4$ thin films were tested in a PEC cell, shown schematically in Figure 6. To perform the PEC tests, a spray pyrolysis produced $BiVO_4$ photoelectrode sample was immersed in an electrolyte solution of 0.5 M sodium sulfate. This sample was electrically connected through a source-meter to a platinum mesh counter electrode, which was also immersed in the electrolyte solution. The photoelectrode under test was then illuminated with light from a solar simulator. The solar simulator provided a light power density of 1030 W/m^2 at the sample through an AM1.5 spectral filter which mimics the spectral characteristics of solar radiation available on the ground. Figure 7 shows the physical setup used to perform the PEC tests in the laboratory.

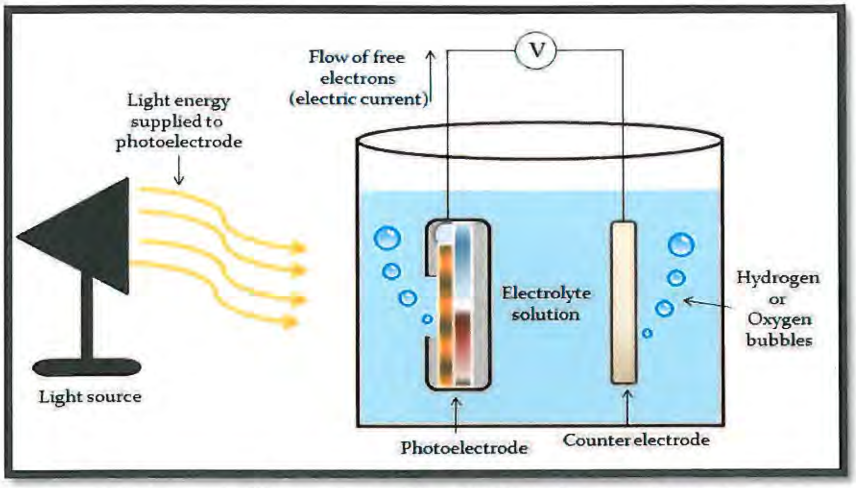


Figure 6. Schematic illustration of the PEC testing configuration.

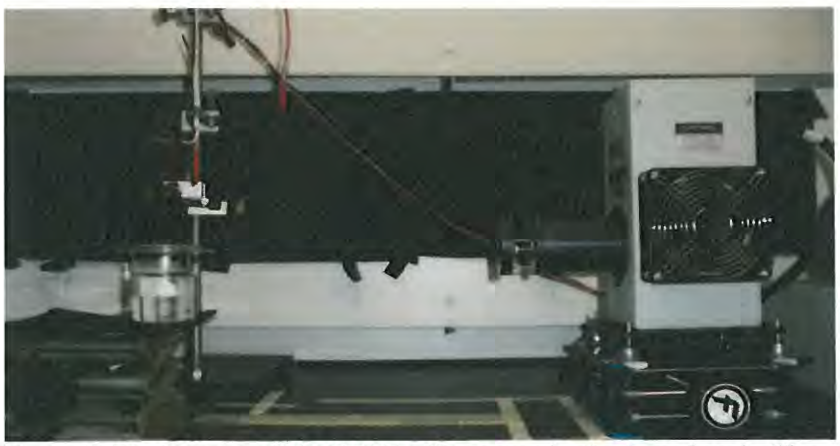


Figure 7. Photograph of the PEC testing setup in the fume hood. The solar simulator is on the right while the PEC cell is on the left.

When illuminated with the solar simulator light, mobile charge carriers were generated in the photoelectrode material due to the photoelectric effect. Depending upon the configuration of the connection with the counter electrode, a photogenerated current develops. The source meter was used to apply an additional potential bias to the photoelectrode to increase the magnitude of this photogenerated current as well as measure the current produced.

The motion of charge carriers (electrons) though the PEC circuit results in oxidation and reduction reactions at the photoelectrode and counter electrode. The amount of hydrogen evolved during this process is directly proportional to the photocurrent that is generated by the PEC cell when illuminated. Therefore, by measuring the produced current and scaling this measurement to the active sample area to obtain a photocurrent density (mA/cm^2), we were able to compare PEC the performance of the different samples produced. Photocurrent densities were measured for all produced samples under short circuit, 0.1 V, 0.5 V, and 1.0 V bias conditions. The open circuit voltage produced by each sample under illumination was also measured.

Tests were performed by exposing the samples to the light source for approximately 20 s. The sample was then blocked from the light source for approximately 20 s. Figure 8 shows the results of open circuit voltage tests for four of the samples. Sample 050 was an undoped BiVO4 sample which showed minimal response. Samples 040 and 043 were doped with Mo and W, respectively. All three of these samples exhibited n-type behavior when exposed to the light – i.e., the open circuit voltage of the sample relative to the counter electrode decreased when exposed to simulated solar radiation. Sample 035 was doped with Ca. The results shown in Figure 8 confirm the NREL theoretical work that Ca doping provides p-type behavior. Unlike the other samples, the open circuit voltage of sample 035 increased when exposed to light.

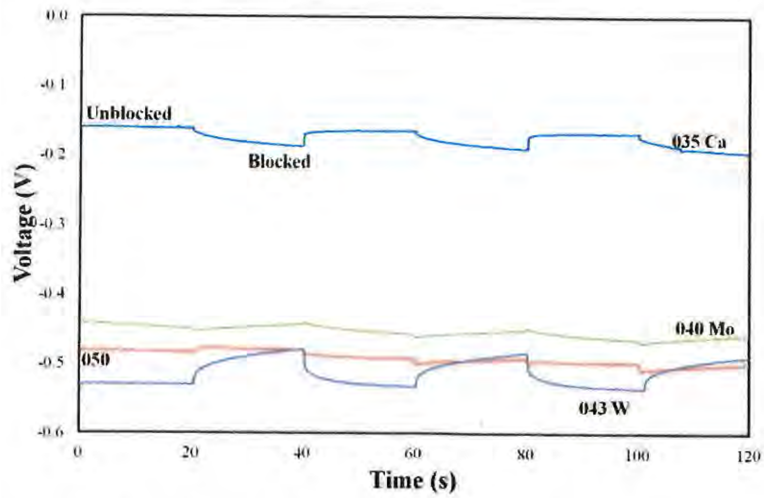


Figure 8. Open circuit voltage tests of four different samples. Sample 050 was undoped, sample 035 was doped with Ca, sample 040 was doped with Mo, and sample 043 was doped with W.

Figure 9 compares the photocurrent densities produced by four of the tested samples. Sample 044 was an intrinsic (undoped) $BiVO_4$ sample. Samples 041 and 043 were doped with W while sample 040 was doped with Mo. All four samples were tested with an applied 0.5 V bias. With the samples tested, a relationship between the dopant type or concentration and the generated photocurrent was not readily observed. In general, samples doped with W tended to produce, on average, a higher photocurrent density than intrinsic samples. An increase in the photocurrent density produced by Mo doped samples over intrinsically doped samples was not observed. Additionally, *some* intrinsic $BiVO_4$ samples exhibited photocurrent densities comparable to W doped samples, such as the intrinsic sample 044 shown in Figure 9. Such results seem to indicate that the morphology and electrical conductivity of the thin-film material, resulting from the selection of precursors and production method, play an important role in determining the PEC performance of the samples.

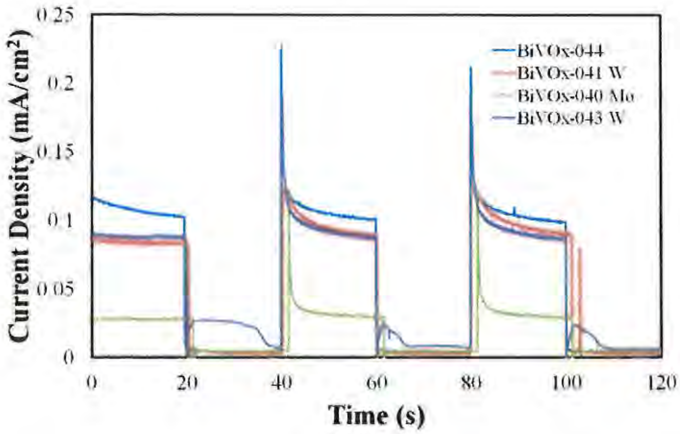


Figure 9. Comparison of the current densities produced by four different BiVO4 samples with an applied bias of 0.5 V.

During the performance period, we did not have the opportunity to test samples made from bismuth nitrate ($Bi(NO_3)_3 \cdot 5H_2O$) and vanadium(III) chloride (VCl_3) or from the chloride compounds ($BiCl_3$ and VCl_3). It is anticipated that thin-films produced from these precursors may exhibit higher electrical conductivity and better PEC performance, both intrinsic and doped. If this is true, a better correlation between doped and undoped sample performance may become more apparent.

G. Conclusions

Results of this investigation demonstrated that doped $BiVO_4$ thin-films can be created using the spray pyrolysis deposition technique. Chemical precursors and additives greatly influenced the morphology of the produced thin-films; however, the morphology of the thin films was not significantly impacted by the inclusion of dopants. Films deposited from precursors containing ethylene glycol and EDTA resulted in thinner, smoother films which provided higher optical transmittance for wavelengths greater than 500 nm, a characteristic desirable for next-generation PV cell tunnel junction materials. Consistent with the theoretical predictions, the addition of Mo and W dopants resulted in n-type behavior while the addition of Ca dopants indicated p-type behavior when tested in the PEC cell. In general, W doped samples generated the highest observed photocurrent densities during PEC testing; however, these results were inconsistent and inconclusive. Further, the high conductivities predicted in theoretical work performed by NREL researchers were not achieved in the samples produced. It is conjectured that the inconsistent PEC test results and high electrical conductivity of the samples was due to the formation of insulating materials at the grain boundaries. The use of different precursor chemicals or a different deposition process may be required to eliminate such effects and improve the material conductivity.

H. Research Contributions and Benefits

Throughout this work, we emphasized a thin film deposition technique, spray pyrolysis, that is low cost. This technique does not require high vacuum environments and uses inexpensive precursor compounds that are relatively environmentally benign. Additional low cost, easy to implement thin film production techniques that are related to spray pyrolysis are proposed for future studies. These manufacturing techniques are capable of being scaled for thin film deposition over large surface areas. Low cost manufacturing techniques such as those being investigated are essential for large scale adoption of solar hydrogen and next generation PV materials.

James Madison University is a recognized leader in applied environmental and renewable energy research and outreach programs throughout Virginia. This work represents a step toward extending that recognition into areas that, while still considered applied research, have significant basic research aspects. This project will enhance the visibility of JMU in the areas of solar hydrogen and PV materials research. In particular, Dr. John Turner and the research group at NREL has expressed interest in this work. The preliminary results of this research have been shared with Dr. Turner and the NREL group that produced the theoretical work suggesting that $BiVO_4$ doping would result in desirable material characteristics. In this manner, this research has contributed to the body of knowledge in the area of PV and PEC material research. We have also established communications with SRI and Dr. Sylvain Marsillac of Old Dominion University (ODU). In the past, SRI has pursued research programs in solar hydrogen, photovoltaics, and spray pyrolysis for thin film deposition. SRI will consider partnering with us if funding opportunities of mutual interest are available. Dr. Marsillac recently joined ODU. He is an authority on thin film PV materials and devices and is receptive to exploring partnership opportunities.

Additionally, James Madison University is committed to undergraduate education and research opportunities. Through this work, and related efforts, numerous students have gained exposure and research experience in this field. Directly through this effort, Brandon Journell, a senior JMU engineering student was funded to participate in guided research with the PIs by participating in the JMU Materials Science REU program during May-July 2011. Additionally, Milan Patel, a recent graduate from New River Valley Community College, was funded through the JMU Materials Science REU program to participate in this work. Brandon and Milan presented their work as poster presentations at the JMU Summer Undergraduate Research Symposium in July 2011. These poster presentations are included at the end of this report. Numerous other Integrated Science and Technology (ISAT) and Engineering students are participating on projects related to this work.

We plan to present this and additional work at the Solar Fuels Symposium at the University of North Carolina in January 2012. Brandon Journell, the undergraduate student funded by this grant, will be involved in preparing and delivering a poster presentation for this meeting. Additionally, students may apply to present this work at the National Conference on Undergraduate Research (NCUR). Finally, we intend to publish the results of this project, in conjunction with results obtained after the performance period, in a peer reviewed journal, such as *Thin Solid Films* or *Solar Energy Materials and Solar Cells.*

I. Future Work

During the performance period for this project we improved our spray pyrolysis deposition system and we succeeded in depositing $BiVO_4$ thin films from several combinations of bismuth and vanadium precursors. We developed the capability to deposit films with microstructures ranging from fully dense to micro-porous. The x-ray diffraction and UV/visible transmission characteristics of our films indicate that we can indeed prepare the desired monoclinic $BiVO_4$ phase. Our efforts to confirm the theoretical model predictions of NREL scientists by preparing highly conductive n-type and p-type material by incorporating dopants have so far proven unsuccessful. However, our initial experiments with a vanadium chloride precursor are encouraging and we are moving forward with experiments in which we will deposit $BiVO_4$ from a precursor prepared from chloride compounds of both vanadium and bismuth. We also intend to adapt a deposition technology that was originally developed to produce thin films of other oxide semiconductors for thin film transistors.

Photoelectrochemical testing of our $BiVO_4$ thin films has shown results that support NREL's theoretical work. The open-circuit photovoltage of tungsten- and molybdenum-doped samples has a negative shift under illumination, indicative of n-type material, whereas the photovoltage of calcium-doped samples has a positive shift, indicative of p-type material. We have not yet produced any samples that show breakthrough performance in terms of water splitting (as indicated by photocurrent measurements). We attribute this to our inability to produce highly conducting samples, though we have not yet tested samples recently made from bismuth nitrate ($Bi(NO_3)_3 \cdot 5H_2O$) and vanadium(III) chloride (VCl_3). We look forward to PEC testing of these samples and additional samples that we will prepare from chloride compounds of both vanadium and bismuth.

In addition to spray pyrolysis, literature reports on the preparation of other thin film materials through a printing or spin coating process followed by heating. Such approaches provide additional avenues that are closely related to the spray pyrolysis technique for producing thin films of $BiVO_4$. This is worthy of investigation because spray pyrolysis and printing followed by pyrolysis are both low cost film manufacturing techniques capable of being scaled up to coat large areas since they are carried out at atmospheric pressure (no expensive vacuum processing is required). Low manufacturing cost is essential to make solar hydrogen and photovoltaic electricity practical.

Finally, we look to extend beyond the production and characterization of $BiVO_4$. In particular, we would like to explore the production and properties of CZTS thin films, produced from Cu, Zn, Sn, and S. Literature has suggested that CZTS films, particularly when doped, are of interest as material for next generation PV cells and PEC applications.

We intend to apply for additional funding for such future research through the NSF Energy for Sustainability program. We will continue to interact with Dr. John Turner of NREL, SRI, and Dr. Marsillac of ODU to seek additional partnerships to further this work.

I. Acknowledgements

Tom DeVore and John Gilje of the JMU Department of Chemistry have worked with us, providing expertise regarding spray pyrolysis precursor selection. Barbara Reisner, also in the JMU Chemistry Department, has assisted with x-ray diffraction measurements. We intend to continue these valuable collaborations.

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Characterization of Thin-Film Bismuth Vanadium Oxide ($BiVO_4$) Semiconductors for Photoelectrolysis Applications

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Abstract

Hydrogen is one of the most promising renewable and sustainable clean energy carriers. For hydrogen energy to be truly "green" it needs to be produced by methods that do not pollute the environment. Work this summer was focused on the methods necessary to develop a characterization system for semiconductor photo-electrodes. Characterization methods include measuring the photocurrent density as a function of the bias voltage, X-Ray diffraction, SEM imaging, and UV/VIS spectroscopy. Along with developing methods for characterizing the semiconductor materials, the testing procedures were refined to ensure repeatability. Bismuth Vanadium Oxide ($BiVO_x$) was characterized using these techniques. $BiVO_x$ was investigated for comparison with theoretical work performed by a group at National Renewable Energy Laboratory (NREL) on dopants and their effect on electrical properties.

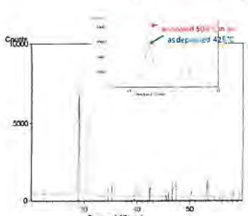
Thin-Film Semiconductors

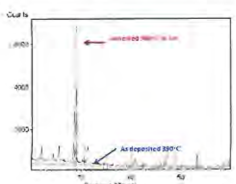
Precursors with various compositions were used to make $BiVO_4$ films. A spray pyrolysis process was used when making the samples for research carried out this summer. The different precursors used result in films with different microstructures, as demonstrated below:

Bi(NO3)3 + NH4VO3+EDTA

Bi(NO3)3+VOSO4

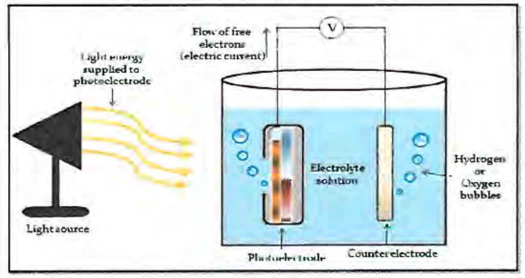
X-Ray Diffraction



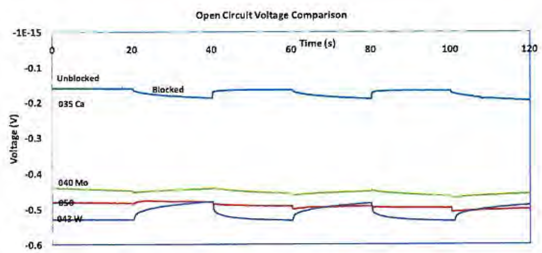


Photoelectrochemical Test Setup

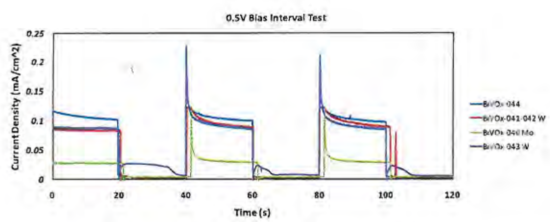
Overview



- The light from the solar simulator illuminates the exposed area of the photoanode.
- Some light is absorbed producing free electrons and holes.
- The holes enter the electrolyte where they participate in an oxidation reaction yielding oxygen.
- Electrons travel through a wire (external circuit) to a metal cathode (Pt) where they participate in a reduction reaction yielding hydrogen.
- The open circuit voltage and short circuit current are measured.
- Current is also measured with applied bias voltage.
- There is a direct relationship between the measured current density and the H_2 production rate.



The above image is a comparison of the effects of doping $BiVO_4$ and the changes in Open Circuit Voltages. The test was carried out using intermittent solar illumination (20 second intervals) from the solar simulator producing 1030 W/m^2. The graph illustrates that Calcium doping causes the sample to be more positive rather than negative when exposed to light.



The above image compares samples with various dopants and their respective current density under 0.5V Bias vs. time.

Sample Data

						Current Densities (mA/cm²)			
Sample ID	Dopant	Hot Plate Temperature:	Deposition Time:	Annealing:	Thickness:	SC	0.1V	0.5V	1.0V
BIVOx-035 Ca	Calcium	440C	25 min	500C Air	-	0.00184	0.00228	0.00339	0.02097
BIVOx-050	-	430C	18 min	500C Air, 375C H2	0.81, 0.78 um	0.00622	0.01191	0.06564	0.21288
BIVOx-051 Mo	3 % Mo	430C	18 min	500C Air, 375C H2	0.37, 0.42, 0.52 um	0.00463	0.00804	0.04992	0.24866
BIVOx-052	Molybdenum	430C	28 min	500C Air, 375C H2	0.23-0.25 um	-	-	-	-
BIVOx-053	Molybdenum	435C	18 min	500C Air, 375C H2	1.3, 1.2, 1.4 um	-	-	-	-
BIVOx-054 Mo	Molybdenum	420C	20 min	500C Air, 375C H2	0.14-0.15 um	0.00288	0.00554	0.02205	0.18997
BIVOx-055 W	3% Tungston	430C	20 min	500C Air, 375C H2	1.23 um	0.00795	0.01172	0.07703	0.35678
BIVOx-056	3% Tungston	425C	25 min	500C Air, 375C H2	0.20 um	0.00527	0.00964	0.03780	0.18355

•This is a sample of the data that we have collected over the course of the summer and the PEC testing.

Conclusions

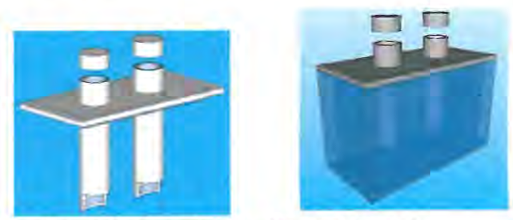
Even though the study is still ongoing, we have observed some trends in the sample characteristics:

- Ca doping tends to make the sample p-type which is consistent with the theoretical predictions from NREL. Also a higher conductivity was theorized, however, a higher conductivity was not apparent in testing.
- Samples annealed in %3 H_2 yield a higher current density
- Tungsten doped samples exhibit higher current densities in nearly all cases

Future Work

Future work will mainly be carried out to investigate the following topics:

- Build a Universal Testing Apparatus
- Try different percentages of the dopants
- Test alternative precursors
- Perform stability tests for the material lifetime



•Part of Universal Testing Apparatus outlining electrode support

References

•Zhebo Chen and Thomas F. Jaramillo et al., J. Mater. Res., Vol. 25, No. 1, Jan 2010
•Mingtao Li, Liang Zhao, Liejin Guo; International Journal of Hydrogen Energy 35 (2010) 7127-7133
•Wan-Jian Yin et al., National Renewable Energy Laboratory, Physical Review B 83, 155102 (2011)

Acknowledgements

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- DOD-ASSURE/NSF-REU grant # DMR-0851367
- Dr. Barbara A. Reisner, Professor, Chemistry
- Undergraduate Students: Brandon Lancaster, Ashley Lambers, Milan Patel, Patrick Nutbrown, John Murdock, Bradley Wenzel

The views expressed are those of the authors and do not necessarily reflect those of the sponsors.

DEPOSITION OF $BiVO_4$ THIN FILMS FOR PHOTOELECTROCHEMICAL WATER SPLITTING

Milan Patel, Dr. David Lawrence, Dr.Keith Holland

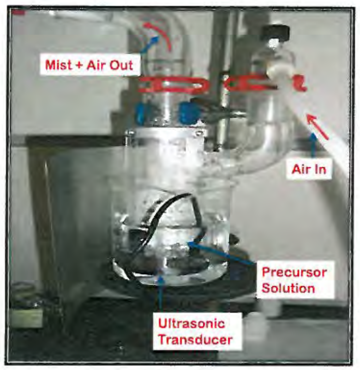
JAMES MADISON UNIVERSITY

Abstract

Bismuth vanadate ($BiVO_4$) has been proposed as a photoanode for photoelectrochemical water splitting to convert solar energy into hydrogen for future renewable energy applications. BiVO4 absorbs more of the visible spectrum than many early materials (e.g TiO_2, WO_3). We prepared thin films of $BiVO_4$ using the spray pyrolysis technique. Films were made using different precursors in efforts to vary film morphology and doping. The resulting films were characterized by measuring their thickness and UV/Visible light transmission spectra. Films were examined with the scanning electron microscope. We will describe the spray pyrolysis technique and show how the choice of precursors affects the morphology and optical transmission of the thin films.

Film Deposition by Spray Pyrolysis

We used an ultrasonic transducer to produce a mist from the precursor solution. The bismuth source in the precursor solutions was $Bi(NO_3)_3 \cdot 5H_2O$. NH_4VO_3 and $VOSO_4$ were used as vanadium sources.



The precursor mist is transported by a flow of air to the deposition chamber where it is directed at the substrates. Glass, SiO_2, and ITO coated glass heated to 425 °C were used as substrates.

A motor scans the nozzle back and forth to deliver the precursor mist to the hot substrate surface.

Precursors

Precursors are prepared from aqueous solutions of the following compounds;

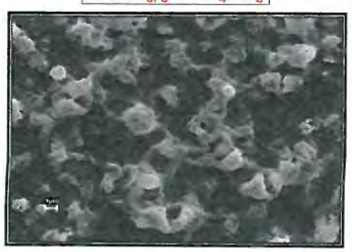
Bismuth	$Bi(NO_3)_3 \cdot 5H_2O$
Vanadium	NH_4VO_3 or $VOSO_4$

In some experiments, the following dopents were added during the deposition process.

Ammonium Molybdate	$(NH_4)_6(MO_7O_{24}) \cdot 4H_2O$
Sillicotungstic Acid	$SiO_2 \cdot 12WO_3 \cdot 26H_2O$
Calcium Nitrate	$Ca(NO_3)_2 \cdot 4H_2O$

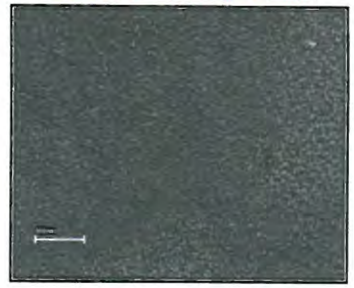
Film Characterization

$Bi(NO_3)_3 + NH_4VO_3$

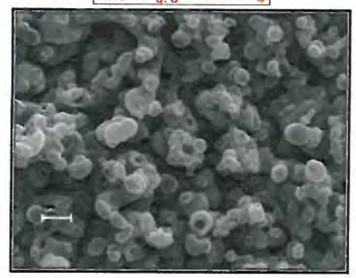


$Bi(NO_3)_3 + NH_4VO_3$ + Ethylene Glycol

$Bi(NO_3)_3 + NH_4VO_3$ + EDTA

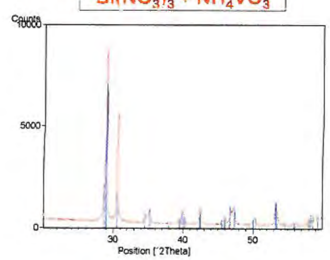


$Bi(NO_3)_3 + VOSO_4$

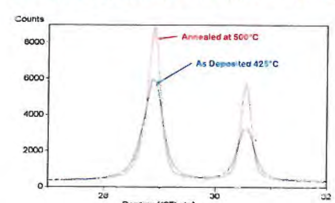


X-Ray Diffraction

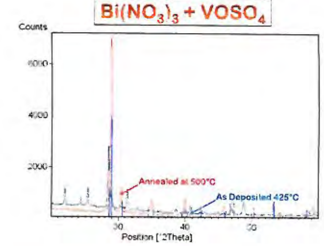
$Bi(NO_3)_3 + NH_4VO_3$



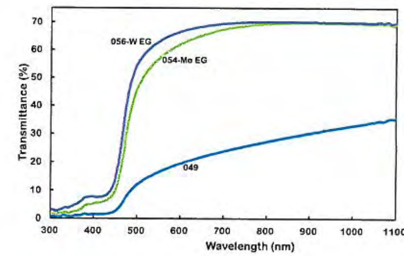
Comparison of annealed and unannealed samples



$Bi(NO_3)_3 + VOSO_4$



Transmittance Spectra



Conclusion

Spray pyrolysis is an effective deposition technique for $BiVO_4$ films. The morphology of the films depends on choice of precursor solution. Ethylene glycol and EDTA additions produce smoother films that have greater transmittance.

References

Mingtao Li, Liang Zhao, Liejin Guo; International Journal of Hydrogen 35 (2010) 7127-7133.
Wan-Jian Yin et al., National Renewable Energy Laboratory, Physics Review B 83, 155102 (2011).

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We also thank Dr. Barbara Reisner, Brandon Journell, Brandon Lancaster, Mark Starnes and Casey Flanagan for their assistance.

Valley 25x25
Project Report

Two-phase Energy System

Project period: 5/14/2012 – 8/15/2012

Dr. Jacquelyn K. Nagel
J. Ben Condro

Two-phase Energy System

Executive Summary
Energy consumption and generation is a major issue in the world today, which directly affects society on many levels. Thinking and planning for tomorrow's energy needs impacts public policy, public utilities, large and small businesses, what is available on the market and subsequently the public. Current technologies for generating clean, renewable energy at a residential unit are costly and require the use of chemical batteries, which are often cited as the major weakness in a renewable energy system. Chemical batteries can leak toxins, be difficult to recycle and require replacement about every 5 years due to degradation. This project aims to address the major weakness of renewable energy systems by replacing the chemical battery with a fluid-mechanical "battery."

Over the project reporting period research and development of a two-phase energy system that provides clean, renewable energy for residential use without the use of chemical batteries was undertaken, and gave positive results. The research objective of the two-phase energy system is to explore the technical challenge of sustainability as it relates to solar energy production, storage and consumption. A fundamental approach to decreasing the environmental impact of a solar energy system is to reduce the toxic, non-recyclable and recyclable, materials within, and maximize the lifetime of each component to reduce waste. This project focused on meeting the goal of providing electrical energy during both day and night without the use of chemical batteries.

A traditional photovoltaic solar system that collects light from the sun to produce electrical energy comprises the first phase. Phase two aims to replace the traditional battery bank found in solar energy systems with a fluid-mechanical energy system design that stores potential energy as a liquid. The gravity fed release of a stored liquid during the lunar cycle is used to generate energy. The desired output is 12 VDC to match the capabilities of a chemical battery. Over 15 concepts for energy generation during the lunar cycle were created. Four concepts based on the strategies of rotation, momentum, impact and return, and pressure difference were chosen for further exploration to assess feasibility of the ideas. Prototypes for the rotation and momentum concepts were constructed and tested. Additionally, all individual system components were tested and validated before the entire system was contracted.

A scaled down version of the two-phase system with the rotational energy generation strategy was constructed, as well as a traditional solar energy system with a battery for comparison. System wiring meets electrical code standards and safety guidelines. Additionally, both systems are built on mobile platforms so each can operate under similar sun conditions. Preliminary results of the rotational energy generation strategy for the lunar phase produced about 4 VDC. Energy is lost to sources of mechanical friction, and height of the stored liquid was constrained to keep the system mobile. Future tests will vary multiple factors to increase output of the rotational energy generation strategy. Although output of the two-phase energy system is not at the desired capacity, the research performed over the reporting period shows positive results and motivates further research. Further analysis and prototyping of the two-phase energy system will be undertaken as a two-year engineering capstone project.

Two-phase Energy System Report
Table of Contents

1. Introduction & Motivation

The research objective of this proposal is to explore the technical challenge of sustainability as it relates to solar energy production, storage and consumption. This proposed research will address the technical challenge of sustainability through the design of a two-phase, clean energy system for residential use that generates and stores electrical energy from solar energy for use both day and night without the addition of traditional battery technologies. For the first phase, a traditional photovoltaic array system collects light from the sun to produce electrical energy, as shown in Figure 1. To the store and use the energy during the lunar cycle, a fluid-mechanical energy system design will be explored as phase two. The fluid-mechanical system will provide electrical energy at night by storing the energy generated from the sun as potential energy in liquid form. This research will result in an efficient, fluid-mechanical based "battery" system, inspired by sustainable energy system practices, that replaces the chemical battery in Figure 1.

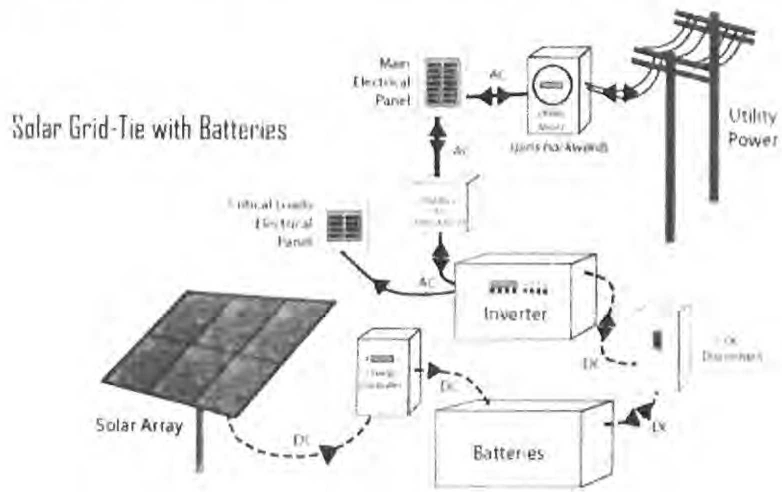

Figure 1. Photovoltaic System with Batteries and Tied to the Grid [adapted from 1]

A fundamental approach to decreasing the environmental impact of a solar energy system is to reduce the toxic, non-recyclable and recyclable, materials within, and to increase the lifetime of each system component. Recycling programs for chemical batteries are more common nowadays and in many cases mandatory [2]; however, they are still costly at roughly $1000-2000 USD per ton of battery waste [3]. Since 2000, lead-acid batteries alone generate over 2.0 million tons of waste each year [4]. Although recycling rates of the lead contained within lead-acid batteries have reached nearly 100% over the past decade, roughly 20,000 tons of battery waste, such as plastic, electrolyte and other nonferrous materials, entered the municipal waste stream in 2008 alone [4]. Not all renewable energy systems utilize lead-acid batteries, which could lead to hundreds of tons of hazardous waste entering the municipal waste stream that is not reclaimable. Beyond recyclability, chemical batteries present a number of other disadvantages including: (1) corrosion concerns, (2) off-gassing, (3) temperature induced variability, (4) stochastic charging and state-of-charge, (5) high cost, and (6) strict tolerances for charge controllers [1, 5-14]. Moving away from traditional chemical battery technologies means that customers do not have to deal with these concerns, but could also increase efficiency of the overall solar energy system by more consistent operation. This equates to less money spent on replacement components and decreased waste generation, which is the most effective method of waste reduction [15]. Comparison of the efficiency between traditional photovoltaic energy systems with chemical batteries and a two-phase environmentally friendlier system without chemical batteries will identify design opportunities that promote holistic, sustainable design practices. Exploration of these design opportunities will lead to a system design that reduces chemical waste associated with traditional battery technologies.

To move away from chemical batteries as a method for energy storage, an innovative fluid-based energy system to store energy generated during the solar cycle as potential energy for supply during the lunar cycle is explored. Liquid is pumped into a reservoir that is at a certain height from the ground during the day. As a gravity fed system, the stored liquid is released and guided to the device that will generate energy during the lunar cycle. Pumped storage is not a newly developed concept; however, it has only been implemented on a large scale. Power plants have used pumped storage as a backup system to meet demand surges [16], and offer engineering design inspiration for a small-scale, residential system.

A research group investigated the viability of replacing partial battery storage with a micro-hydraulic system, similar to power plant pumped storage, on the Donoussa Island in the Aegean Sea, Greece to power a small village [17]. Water is pumped roughly 200 m above sea level during the day with the extra energy produced from a photovoltaic system. During the night, the water is released to a lower reservoir and produces energy by rotating another pump in reverse, thereby using a motor as a generator [17]. Manolakos et. al found that the micro-hydraulic system was successful at producing electrical energy, but stated that the efficiency could have been increased if an actual turbine were used [17]. Overall, the micro-hydraulic system was simple, had low maintenance and did not require specialized skills to perform system maintenance. Additional relevant research is focused on solar powered water pump systems [18-23]. Majority of solar powered, water pump systems address lack of water in developing countries and aim to decrease deaths and illness. Regardless, the information will assist with designing the pumping portion of the system and sizing of the pump for the proposed research.

a. Research objectives

The overarching objective of this research is to explore the technical challenge of sustainability as it relates to solar energy production, storage and consumption. The design and development of a two-phase energy system addresses the research objective by providing electrical energy during both day and night without the use of chemical batteries. Phase one is a traditional solar array that collects sunlight to produce electrical energy. Phase two is as a fluid-mechanical energy system to store energy generated during the solar cycle as potential energy for supply during the lunar cycle.

Phase one of the system, the photovoltaic phase, takes in solar energy and converts it to electrical energy for use in a home. The electrical energy is distributed throughout the home to power appliances, the hot water heater, and anything else plugged in to an outlet. Energy production by the photovoltaic phase beyond the electrical demand of the home is used to pump a liquid (i.e., rain water, liquid that can resist freezing) from a lower reservoir to an upper reservoir. The upper reservoir is at an appropriate height to store the liquid as potential energy for the production of electrical energy during the lunar cycle. After the photovoltaic phase of the system can no longer generate electrical energy for the day, the second phase of the system, the fluid-mechanical phase, initiates. During the lunar cycle, liquid within the upper reservoir is released to flow back to the lower reservoir. The flowing liquid will be utilized to generate electrical energy. The absence of chemical batteries in this renewable energy system requires the home to also be grid-connected. When electrical energy production is below the electrical demand of the home, energy is supplied from the grid. The advantage of a grid-connected renewable energy system is the ability to make a profit and reduce power plant loads when excess electrical energy is produced. On days when more energy than is needed to meet the demands of the home and pumping mechanism is produced, the energy can be supplied to the grid, and further reduce fossil fuel consumption.

The two-phase energy system directly correlates to a reduction in pollutants at three points in the system's lifecycle: reduction of pollutants in the home, by a power plant and by chemical batteries. The renewable, clean energy system explored in this research leads to less fossil fuels burned at a power plant to power a home in an urban area. Less chemical waste is created during battery manufacturing, consumption and recycling because the system does not utilize chemical batteries. By replacing batteries with components that comprise a fluid-mechanical "battery", simpler recycling procedures can be utilized to increase the likelihood that system components are recycled at the time of disposal. The research objectives of this project are:

i. explore strategies for energy production during the lunar cycle using the stored potential energy in liquid;

ii. removal of hazardous chemical batteries from habitable areas of the home;

iii. reduction of chemical battery waste - during manufacturing and recycling;

iv. reduction of fossil fuel energy needed for an urban area; and

v. inspire sustainable design practices.

The innovative aspect of the two-phase energy system is the strategy for energy production during the lunar cycle. Production of electrical energy during the night using stored energy indirectly generated from a photovoltaic energy system without chemical batteries is a novel concept for residential, renewable energy systems. Wind power has been added to homes to supplement photovoltaic energy; however, that is not always feasible for an urban area.

b. Broader Impact

The two-phase energy system project addresses the pillars of sustainability in multiple ways throughout its full lifecycle–design to implementation to disposal. With respect to the social pillar, safety is very important. The proposed system increases personal safety by removing potentially toxic batteries from the home. This prevents exposure to chemical battery off-gassing, corrosion, fire-hazards, and keeps children from touching the batteries. Additionally, the approach of using a fluid-mechanical "battery" to store potential energy instead of chemical batteries will reduce the overall cost of the system. Not having to replace costly components during the entire lifecycle of the two-phase energy system will save money; addressing the economic pillar. Along with designing a system that saves money, the intent is to design a renewable energy system that the average person can install and maintain. Thus, the proposed system will allow the average person or family to live a sustainable life without having to sacrifice lifestyle. The technical pillar is addressed by the two-phase energy system design in that it embodies a simple approach to renewable energy that can last for several years with routine maintenance.

Economically, the two-phase energy system will make renewable energy affordable for the average person or family, but also save money in the long run. By designing a system that can last for several years with routine maintenance increases the likelihood of achieving a return-on-investment and making money in the subsequent years. Majority of expenses will be for procuring and installing the system. Maintenance costs will be comparable to those of a solar photovoltaic system that is grid-connected, without chemical batteries. The advantage of a grid-connected renewable energy system is the ability to make a profit for the owner and reduce power plant loads when excess electrical energy is produced. On days when more energy than is needed to meet the demands of the home and pumping mechanism is produced, the energy can be supplied to the grid, and further reduce fossil fuel consumption. The potential to produce more electrical energy than is demanded, which can be fed back into the grid for a profit will directly benefit the user, both ecologically and financially.

Many of the aforementioned benefits related to social and economic pillars also relate to the sustainability pillar of environment. By designing a system that can last several years reduces waste from the start, as prescribed by the EPA [15]. Replacing the traditional chemical battery with a fluid-mechanical equivalent reduces the battery waste that is put into landfills, which cannot be recovered through recycling. Reduction of battery usage reduces the amount of toxic chemicals used to produce products. Furthermore, this reduces the amount of waste generated from recycling and reclaiming used chemical battery materials. With the use of solar energy in an urban environment, and renewable energy sources in general, less fossil fuels are required to generate energy at power plants, which reduces the carbon footprint. Lastly, by utilizing a fluid to store potential energy, the two-phase energy system could be modified to collect and use rainwater in wet climates to generate electricity during the day and night. The proposed system offers a wide range of benefits that support the pillars of sustainability.

For educational purposes, this project will be used as a design case study to teach sustainable design practices in the engineering design course sequence that all engineering majors take at James Madison University. The project will also be made available to showcase and promote sustainable initiatives when external people visit JMU (e.g., open house, capstone day, girl scouts badge day). Additionally, an effort will be made to showcase the two-phase energy system project across the STEM disciplines of JMU to encourage sustainability.

As an interdisciplinary project, knowledge of electrical engineering, mechanical engineering and economics will be needed to complete this project. In efforts to achieve the goals stated above, the student working on the project will be expected to learn concepts outside their expertise and gain an understanding of each project element. This will broaden the knowledge and experience of the student, but also prepare the student to solve an interdisciplinary problem.

c. Deliverables

The key deliverables of this project to meet the research objectives and broader impacts are:

1. design of the innovative strategy for energy production during the lunar cycle utilizing stored potential energy in a fluid;
2. working prototype of the two-phase energy system;
3. cost analysis determining the return-on-investment; and
4. experimentally determined efficiency analysis.

2. Research Approach

The approach taken to develop the two-phase energy system is the engineering design process, which includes the following phases: Planning, Concept Development, Embodiment (which includes system-level and detailed design), and Testing and Refinement [24, 25]. It is important to note that the engineering design process is not a linear process; rather, it is an iterative, and systematic process that results in a solution to a need or problem. Therefore, the following sections describe the approach and what was achieved for each phase of the design process rather than a procedural format.

a. Planning

During the planning phase of the engineering design process initial research on the project is performed to assist with defining the system requirements, constraints, and necessary resources.

The first part of the planning phase was to inform all involved in the project on what needed to be accomplished and what objectives needed to be met. Once a shared understand was established, research needed to be successful in the project began. The preliminary layout of the two-phase energy system, modeled functionally in Figure 2, was used as a starting point for planning. Initial research focused on renewable energy system design for a residential unit, and determining average residential unit energy needs. From the information gathered requirements and constraints for the project were established. Experimental testing conditions were also discussed at a high level to reduce issues later on in the project.

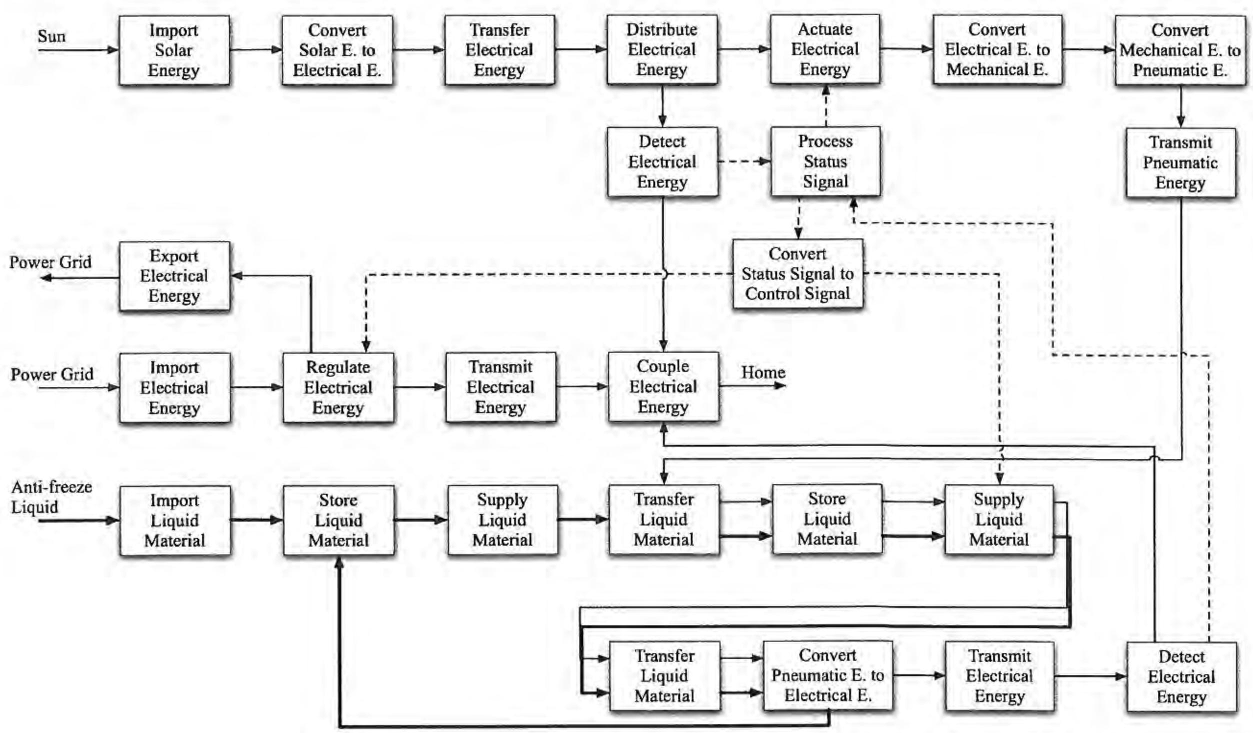

Figure 2: Model of the Two-phase Energy System

Research provided a firm understanding of how traditional residential solar energy systems work as well as identified subsystems and their components were identified. When questions about particular items were exposed, personnel from both the university and vendors were contacted to confirm thoughts or disprove ideas.

b. Concept development

During the concept development phase, concept generation, evaluation and selection occur. Brainstorming, sketching, and research are used to collect and record ideas. All concepts are evaluated against the same criteria and a final set of concepts are chosen for further analysis. Prototypes, analytical or physical, are created to test feasibility of concepts.

Concept development activities that followed the planning phase for this project included concept generation of solutions for the fluid-mechanical energy generation strategies of Model 2, proof-of-concept models to test conceptual ideas, determination of the most viable solutions against the requirements and constraints, and determination of the system model to finalize the design. Concepts were also iteratively refined to define the design and layout of the two-phase energy system.

c. Embodiment

During the embodiment phase of design sub-systems are identified, geometric layouts are created, and components to create the design are chosen. Preliminary engineering drawings and schematics are developed. Alpha level prototypes are constructed to show final geometry and sub-system integration.

After completion of the first two design phases, the identified system components are chosen, purchased or created, and the system integration is considered. Both off-the-shelf solutions and novel conceptual design solutions to implement the fluid-mechanical "battery" of phase two were explored. Once components were purchased a bill of materials was created. For this project two BOMs were created; one for the traditional system (Model 1) and the other for the two-phase energy system (Model 2). A third BOM was created to capture all items purchased for the project. Construction of the experimental set-up based on requirements and constraints determined during planning also began during this phase and carried over into the testing and refinement phase.

Due to the time constraint and the experiential nature of this project geometric layouts, engineering drawings and schematics in software were not created. Rather, time was focused on creating the working prototypes.

d. Testing and refinement

During the testing and refinement phase, physical prototype(s) are tested for desired functionality and data is taken for analysis. Refinement of the design occurs to create a beta prototype, and then testing is repeated. Testing and refinement loops occur until desired output and system requirements are achieved to create final design.

Testing occurred at many points during the project. Informal testing of proof-of-concept prototypes allowed for feasibility checks. As individual components were purchased simple tests to check functionality and working conditions were performed. This also helped with troubleshooting during system integration and testing. The experimental testing conditions and set-up were also finalized. Experimental tests assist with determining viability and efficiency, and allow comparison to a traditional solar energy system with chemical batteries.

Due to the time constraint cost and efficiency analyses with data captured from experimental tests were not performed. Not enough data was captured for comparison.

3. Results

In this section the results of the research approach are presented. The format follows the four major phases of the design process. All discussion of the results are reserved for the Discussion section.

a. Planning

Research focused on renewable energy systems for a residential unit is summarized in Table 1. Table 1 organizes the information collected on traditional residential solar energy systems, their subsystems and their components, for grid and non-grid tied systems [26-30].

Subsystem or Component	Summary
Photovoltaic (PV) Panel	Solar panels generate electricity from the sun using the photovoltaic cells which make up one panel.
PV combiner unit	Acts as a junction box connecting the modules in the desired configuration.
Protection unit	Houses a DC switch to isolate the PV array and anti-surge devices to protect against lightning. Alternatively, these functions may be incorporated directly into a PV panel or inverter.
Inverter	Converts DC power from the PV array it into AC power at the right voltage and frequency for feeding into the grid or supply domestic loads.
Energy-flow metering	Used to record the flow of electricity to and from the grid.
Charge Controller	Manages the charge and discharge of the battery to keep the battery pack from being overloaded and protected from faulty loads.
Chemical Battery	Store the electrical power in the form of a chemical reaction. Come in three types: Flooded, gel and AGM.
Fuse Box	This is the normal type of fuse box provided with a domestic electricity supply.
Electric Load	Domestic electrical loads include lighting, TV's, and heaters

Research into the average residential unit energy needs revealed that loads for a residence average 32,000 Watts per day, or 958 kilowatt-hours (kWh) per month [31]. These numbers would be used for designing a non-grid tied system. Research into the capacity of a residential grid tied solar energy system revealed an average of 5700 Watts per day [32].

From this research, the constraint on the type of energy system was defined. The two-phase energy system will be a grid tied system. Thus, a system requirement is to produce 5700 Watts per day. Additionally, the goal is to replace chemical batteries which are typically 12 Volt systems. Two requirements emerge from this goal. The two-phase energy system will be a 12 VDC system and the system output will be 12 Volts DC at 1 Amp to match chemical battery capacity. Therefore, the constraint on budget is the two-phase energy system cannot cost more than a traditional solar energy system.

Once project requirements and constraints were set, planning for the deliverables began. As the project calls for solar energy to be used during daylight hours and to discover ways to harvest energy during the lunar cycle, it was resolved to build two different solar energy systems during the project for testing and comparison purposes. The system representing a traditional residential solar energy system with a photovoltaic panel, charge controller, battery and load is referred to as Model 1. The system representing the experimental, two-phase solar energy system with a photovoltaic panel, two reservoirs, piping, pump, and an energy generation device is reffered to as Model 2. The additional subsystems and components of Table 1 will not be considered in this research as they relate to the AC power conversion and protection, which is outside the scope of this project.

To ensure that experimental testing conditions are similar for both systems, they should be built on mobile platforms so they can be put outside in the sunlight at the same location and orientation. Two requirements emerge from this testing goal. Both Model 1 and Model 2 will be built on mobile platforms, and solar panels on each will be mounted at the same angle. Meeting these requirements impacts the size of the physical working prototypes. Therefore a constraint is defined form both the Model 1 and Model 2 systems that they must be able to fit through standard double doorways (height and width).

b. Concept development

Concept development occurred in three distinct iterations. The first iteration involved brainstorming as many concepts as possible for energy production during the lunar cycle using the stored potential energy in liquid. The second iteration narrowed in on four different strategies of energy generation that could be feasibly tested. This is also when proof-of-concept prototypes were constructed. The third iteration focused on refining the promising concepts from the second iteration and defining the two-phase energy system layout.

First concept development iteration

The following concepts and their descriptions are pulled directly from design notes. The wording and language was not changed to preserve the original thought processes during concept generation.

1. **Concept 1 - fly wheel -** Water will fall down a tube or inside of a pipe to a designated distance and location. At the bottom of tube/pipe will be a flywheel or turbine which will spin as the water hits it. This turbine/flywheel will spin a generator to power electrical devises and output DC current. The water will never be lost because it will be collected after it hits the turbine/flywheel which will be over top of a bucket. This bucket will collect the water and will act as a holding tank. A pipe will be attached to the bucket to suck the water back up by a generator. The water will then be recycled and fall down the original pipe to start the process over.
2. **Concept 2 - turbine/different setup -** Same as concept 1 but change it up for a different approach. A flywheel can be good if it is exposed such as if it were outside attached to your house. If that is not the case, a turbine would be more appropriate because it can be contained inside of a closed area or underground. I think this is better than concept 1 but gives us two options. Turbines can be manipulated and placed in many different areas unlike a flywheel
3. **Concept 3 - up down side to side -** A seesawing effect where water or momentum moves back and forth at a constant rate and nothing interferes with it. This could be a

hydraulic system of some sorts. Or have a vertical seesaw that would have a bucket on each side. Water fills one side then moves to the next. Would power the generator when it goes up and down. Would need a shut off value to stop the water when moving from side to side. Maybe on each end, have it like Morse code to generate electricity or the beam going up and down could generate electricity. The water could fall on to the beam and fill a bucket. Once the bucket is filled, it will fall to touch the wire. When it hits the wire, the water will empty and the other side will fall because it is weighted. Or, have the wheel that holds it together be connected to the generator and have it move to convert power.

4. **<u>Concept 4</u>** - This idea calls for compressed air similar to a bike pump that could release energy when instructed (Figure 3). Water falls to press and release air. Then it goes back up to collect air and water falls again (Figure 4). We would need to setup some kind of pump to could generate a force by pushing down on air molecules. Water would hit the pump and cause it to compress, which in turn would pump out air at the other end. The air would then turn a generator that would be connected to the house. How do you get the pump back up to start over? Maybe have it attached to a spring or rubber band? If water flows at constant rate, it would ensure a constant force/pressure. Would this idea bring short laps of no electricity when it is coming back up the pipe and filling up with air again? With falling water comes high pressure in the pipe line. This could be used to our advantage if we can use this forceful pressure to push down on a pump to power the generator. What if you had a bucket that gets filled with water as it falls down. After reaching a certain limit of weight or capacity, it falls down; compressing the pump. When it hits the bottom, the bucket empties and comes back up because the spring holding it now has the force to push back on it, or have a clip to hold and release it. Could have a set timer.

Figure 3: Screen shot taken for inspiration for an impact and return strategy[1]

Figure 4: Sketch for Concept 4

5. **<u>Concept 5</u>** - Could use a generator that has electromagnets in it. Hydroelectric or some kind of magnetic storage in magnetic fields. Chapter 11 of Gazarian. In the book they

[1] http://www.youtube.com/watch?v=pTX8UojGhDc

talk about superconducting magnetic energy storage. However, they work with helium. Electromagnets need electricity in order to work so this might not be feasible?

6. **Concept 6** - Maybe have two magnets in same charge to push away from each other. When two magnets face each other, they push apart and will continue to do so. If put on a wheel of some sort, they will push apart from each other, creating a motion that could turn a turbine or something.
7. **Concept 7 - Heat and Cooling mechanism**[2] - Have the sun heat water and boil it or something. Only problem is that we are not trying to heat water or boil it. This would take too much time and energy would he lost. Could have a chemical reaction due to heat or cooling effect?
8. **Concept 8 – Steam** - This would need a flywheel or a turbine. However, we are not trying to heat water and boil it. See heating and cooling mechanism.
9. **Concept 9 - Hydrostatic Pressure** - This is like the bucket I did in ENGR 112. Not sure how this would generate electricity but can easily get water up a pipe to something else. However, the spout of the pipe where the water comes up and out must be below. Not sure which one but this may not work because of the location of the pipes and the water.
10. **Concept 10 - Back and forth motion** - What about a lever that goes back and forth? A pully system could drive a arm back and forth and at the bottom of it, it could move a lever that generators electricity.
11. **Concept 11 - Vibrations** - How would you get something to vibrate and how would you harness this?
12. **Concept 12 - Seesaw** - A seesawing effect where water or momentum moves back and forth at a constant rate and nothing interferes with it. This could be a hydraulic system of some sorts.
13. **Concept 13 - Water Hose** - What if we had steady flowing water, and made it converge into a small opening like when you put your finger on a hose? Also, like the game when you shoot water into a hole and make the indicator rise until it hits the top and you're the winner.
14. **Concept 14 - Suction** - If we have water falling which turns a flywheel or a turbine of some kind, then if we created a suction or a vacuum then we could use that to generate power for the system.
15. **Concept 15 - Fan Blades** - What about a fan blade that moves when water hits it? It would be like cutting the water into pieces but the water is what moves the blades and powers the generator. If the water flows at a constant rate, then the blade will spin for the amount of time the water falls.
16. **Concept 16 - Electromagnetic spun in a generator** - Have two magnets, both positive, places a distance apart to repel each other. Then have a particle between them to generate a magnetic field and harness that energy for our system.
17. **Concept 17 - Thermochemical** - Use a turbine powered by steam but from chemical reactions.
18. **Concept 18 - Piezoelectric** – Compression of a piezoelectric material causes the creation of voltage. Could the force of water falling create a large enough force to create usable energy?

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[2] http://www.youtube.com/watch?v=D1XyR3YOVZQ&feature=related

Second concept development iteration

Four concepts based on the strategies of rotation, momentum, impact and return, and pressure difference were chosen for further exploration to assess feasibility of the ideas. Concepts based on impact and return and pressure difference were determined not practical or feasible for the project through detailed research and simple tests, respectively. The rotation and momentum concepts were determined to be feasible and prototypes for the rotation and momentum concepts were constructed and tested.

The following concepts and their descriptions are pulled directly from design notes. The wording and language was not changed to preserve the original thought processes during concept generation.

<u>Concept 1 Classic Turbine</u>

There are two main types of turbines which include impulse and reaction turbines. Both are used for different scenarios and situations. Let us first define each turbine that could be used and implemented for our project.

Main Turbines

1. Impulse turbines are designed for high head water; that is water that is moving over a long distance and with great height differences; between 200 and 1000m. The Pelton turbine is the most common and most effective turbine for capturing water in this situation with 95% efficiency under ideal situations with little energy lost. A key to this operation is to have the Pelton turbine rotate in the air and not submerged in water [30].

2. Reaction turbines are designed for medium head water; that is water that is moving over a short distance and a lower height difference; below 450 m. The Francis turbine is the most popular one for low head waters. The big difference is this turbine is completely submerged and uses the weight of the water rather than a jet of high-pressured water to turn the blades [30].

3. The Propeller turbines are designed for very low head water such as slow-running, lowland rivers. However, these systems can't produce a constant power because the water may not always be the same. When the water flow drops below 75% of the design rating, the efficiency drops off rapidly. This calls for multiple turbines at major power plants [30].

Before deciding, we first need to know if we want an exposed turbine or a submerged turbine. Along with this, a height must be known to determine the pressure and the speed that the water will be flowing. Also if we want to increase or decrease the flow rate and send it through a nozzle to increase the pressure to spin the turbine. Pumped hydro is when the water falls from one reservoir to another. On the way down, it runs through a turbine that generates electricity. During off peak hours or in our case, during the day, the turbines are reversed and pump the water back up to start the process over again for the next day. The Francis turbine can both generate and pump back water [30]. Regular hydro power only deals with water flowing down stream. A dam is a good example of hydro power. A home garden is similar to pumped hydro.

Description of Design Turbine 1- Starting with the reservoir, this is where we will house all of our water/fluid which will be at the highest point possible to create maximum pressure in the pipes. A pipe extruding from the bottom of the reservoir will be for extracting water/fluid and sending it through the pipes to the turbine that will be placed at a designated distance and location. This turbine will spin as the water/fluid hits it at a force that we will control based upon the nozzle we choose. As this turbine spins, it will be connected to a generator to power electrical devises and output DC current. The water/fluid will never be lost because it will be collected after it hits the turbine which will be over top of a tank. This tank will collect the water/fluid and will act as a holding tank for the water/fluid to be stored until it is pumped back up to the reservoir. A pipe will be attached to the bucket to suck the water/fluid back up by a pump. The water/fluid will then be recycled and fall down the original pipe to start the process over. Figure 5 shows a proof-of-concept prototype that was built to test the design concept. turbine 1 design.

Description of Design Turbine 2- Same as turbine 1 but change it up for a different approach. Since there are different types of turbines depending on the flow, using the Francis or Propeller turbine could be more suitable for slower water and a shorter distance. However, the Francis/Propeller turbine must be completely under water for it to work. This could call for a different setup but basically the same design; only have an additional tank where the turbine would be placed.

Figure 6: Proof-of-concept prototype of the turbine 1 concept

<u>Concept 2 Momentum/Magnetized</u>

This system calls for something to continuously move with laws of conservation of momentum guiding it. We will need to have water/fluid fall on the system or trigger something to start the motion, and then have it run continuously to generate electricity by moving a generator. We will then need to stop it at a specific time.

What holds something back from moving continuously until the end of time?

1. Friction
2. Gravity
3. Weight distribution
4. Viscosity of air
5. Obstructions
6. Outside forces
7. Inside forces

The first idea for this system was to have something oscillate until we told it to stop. While it runs, I wanted to have it contain water and use the water to continue its motion. Then I realize that no outside force will be needed once it starts. But if we were to use this power in our system and wanted to use water/fluid, what could we do? What could this system generate and how to make it run continuously once it starts?

Description of Design- The schematic in Figure 6 is a concept sketch of the system. The system oscillates back and forth using a series of magnets and springs/shocks. Figure 7 shows the proof-of-concept prototype.

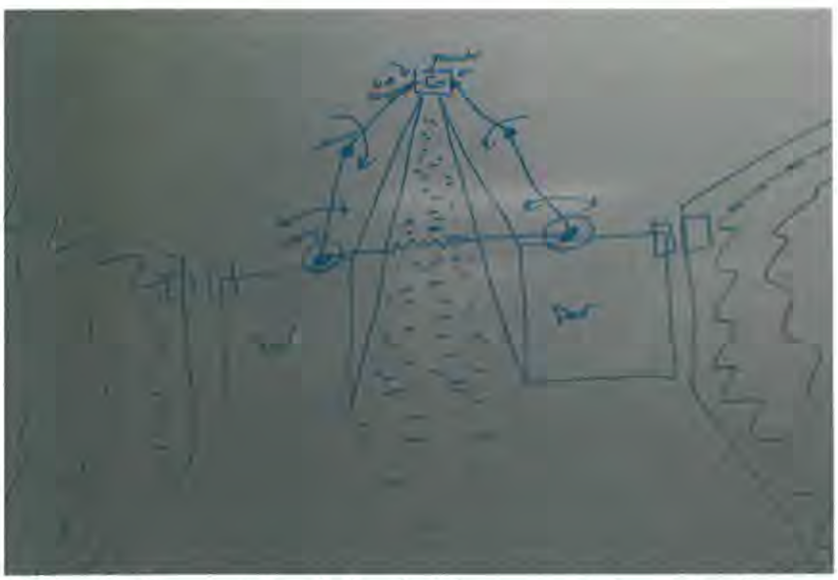


Figure 6: Concept sketch for the Momentum/Magnetized concept

Other thoughts and ideas for future thinking on magnetic system:

What if you have these two things or something similar hit each other then spring back using magnetic. In other words, two wheels turn which drives the panels together, they have magnets on the ends and when they get close enough they push apart. This causes the wheels to turn the other direction until they reach their max. When that happens, they retract once again to move it the reverse direction and then the panels start all over. The wheels are the generator or hooked up to something that will turn the generator. Side note; the panels could be doors that let the water flow in and out of something. Also, the guide that the wheels sit on could also be magnets to push the wheels away or bring them together. The wheels could be connected to opposite turning generators so when one is moving forward and stops, the other starts and moves backward.

- Water triggers something to start moving then momentum or energy keeps it in motion until something else triggers it to stop.
- Maybe have two magnets in same charge to push away from each other. When two magnets face each other, they push apart and will continue to do so. If put on a wheel of some sort, they will push apart from each other, creating a motion that could turn a turbine or something.
- What if you turn on a magnet and it forces another magnet to move away, causing it to turn a generator in circles because it is trying to escape the magnets forces.
- The picture doesn't have to have doors on it; it could be a bar of some kind. The rollers could be lubricated or be magnets too like in the video. Could add spring in middle to bring it out and push out. Also could add spring on ends and attached to walls with the doors. This entire thing could use shocks?

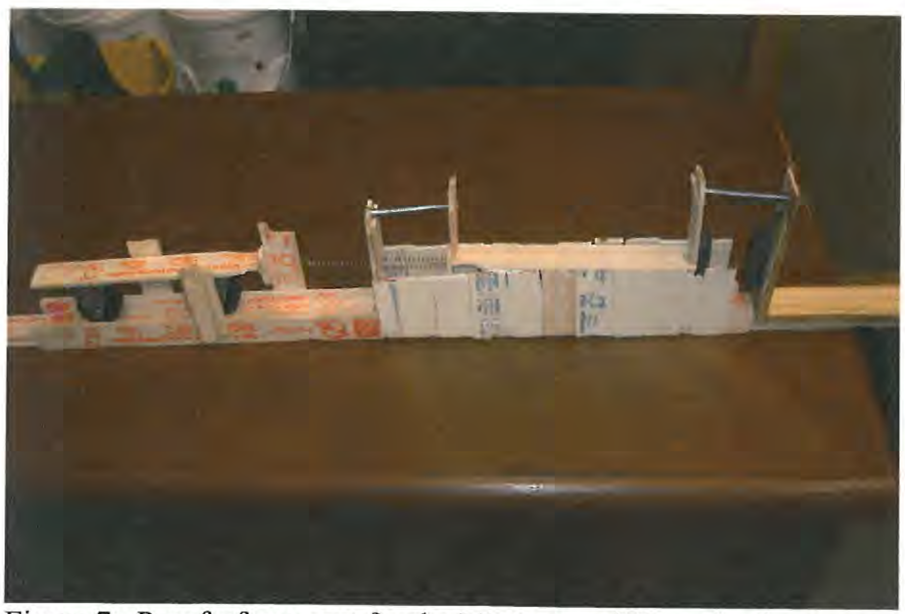


Figure 7: Proof-of-concept for the Momentum/Magnetized concept

<u>Concept 3 Impact and Return</u>

This system calls for the use of compressed air to power a generator by the force generated from a pump action sequence. Bernoulli is well known for his research in fluid mechanics, and he also researched with another method that deals with suction which creates a spray[3]. The image in Figure 4 is a concept sketch of the system concept.

Description of Design - This idea calls for compressed air similar to a bike pump that could release energy when instructed. We would need to setup this pump that could generate a force by pushing down on air molecules. Water would hit the pump and cause it to compress, which in turn would pump out air at the other end. The air would then turn a generator that would be

3 http://www.youtube.com/watch?v=kXBXtaf2TTg

connected to the house. If water flows at constant rate, it would ensure a constant force/pressure. When water falls under certain conditions, it brings high pressure in the pipe line. This could be used to our advantage if we can use this pressure to push down on a pump to power the generator.

We could also have a bucket that gets filled with water/fluid as it filters through the system. After reaching a certain limit of weight or capacity, it falls down; compressing the pump. When it hits the bottom, the bucket empties and comes back up because the spring holding it now has the force to push back on it, or have a clip to hold and release it. Could have a set timer in place and calculate when to release it. When the bucket falls or a force comes down on the material, we could substitute metal or piezoelectric material.

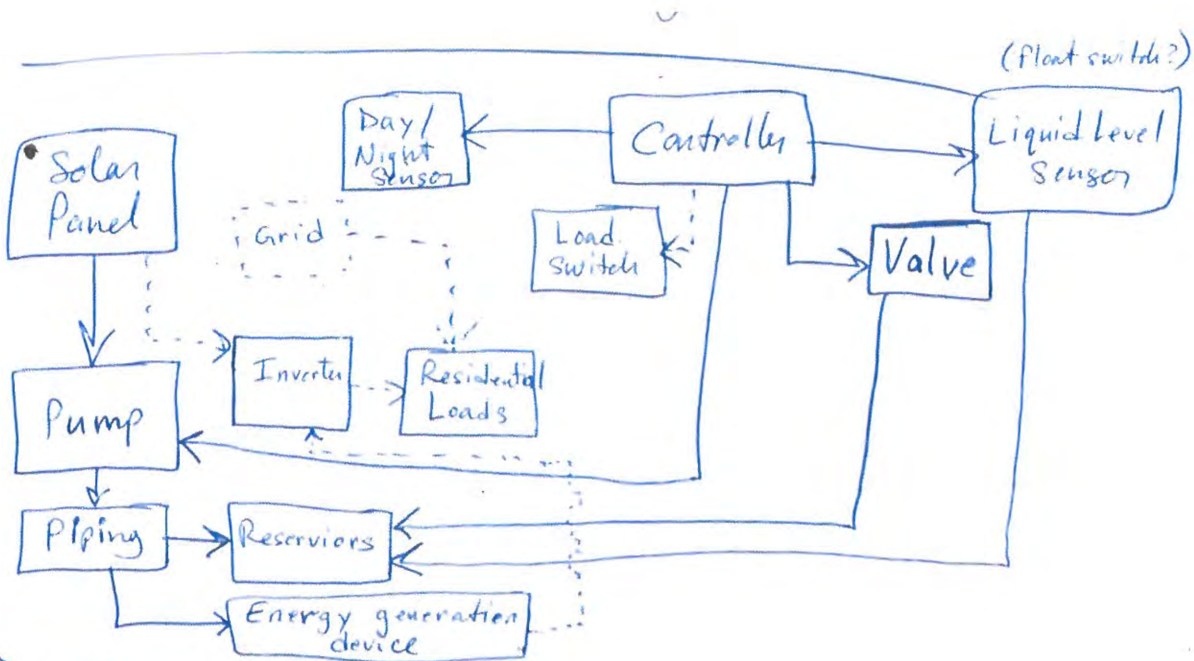
Concept 4 Water hose nozzle

This concept calls for imitating the water force that comes out of a hose when the nozzle is turned or one places their thumb over the end of the hose opening. Could a nozzle on the end of a pipe filled with liquid generate enough pressure to push the water through at a high force? The liquid will be flowing down the pipe from a reservoir, but will there be enough pressure to push it through a nozzle?

Third concept development iteration

The Momentum/Magnetized concept did not work reliably and strong enough magnets were not found. The Classic Turbine concept did work reliably and was well understood. Also, the turbine concept was refined to work with water. Proof-of-concept tests were performed with compressed air. The turbine concept was chosen for embodiment.

The system-level design, laying out the system components to be included to meet the requirements, for the Model 2 system was created. Figure 8 maps out the finalized system layout.



Daytime

- Solar panel is producing electricity
- Pump is on; filling upper reservior
- Once liquid level sensor goes high electricity is diverted to residential loads or power grid

Night time

- Solar panel is not producing electricity
- Day/Night sensor is tripped for night
- Valve opens
- Liquid transfers from upper reservior to lower reservior and generates the necessary electricity to power residential loads
- Once the "Fluid-Mech. battery" is empty, loads would be powered off of the grid until light trips the Day/Night sensor

Figure 8: Two-phase energy system layout

c. Embodiment

Results during the embodiment phase focus on specifying and purchasing components to construct the system.

The standard sizes for solar panels, along with cost, were considered when choosing panels for this project. Solar panel arrays are sized based on number of sun hours, estimated efficiency, and panel watt output. The following equations were used to determine the scale of the working prototype.

Total watts = (Desired watts per day)/(number of sun hours*percent efficiency)

Total number of panels needed = (Total watts) / (panel watts)

Panels at 40, 85, 135, 170, 215 and 240 Watts were considered. In the Harrisonburg, VA area the average number of sun hours per day is four. Panel efficiency is commonly expected to be 70% [28]. A 135 Watt Kyocera panel was chosen for the project. Operating at 70% efficiency for 4 sun hours per day meets the energy requirement (5700 Watts/day) at 1/16 scale.

An image of the traditional solar energy system prototype on a mobile platform is given in Figure 9. The traditional solar energy system was embodied with a single solar panel, charge controller, and battery mounted on a mobile platform. Again, the mobile platform is necessary for easy transportation to an outdoor location for testing. The ProStar PS-15 charge controller was selected for its metering capability of the panel output and the battery charge. The Werken 55 amp-hour battery was selected because it was rated for 12 Volts, it could be purchased locally and the amp-hour rating is a typical size for a residential solar energy system. All system wiring meets electrical code standards and safety guidelines. A simple electrical load of an LED and 5VDC motor was also constructed to test the output of the panel and battery.

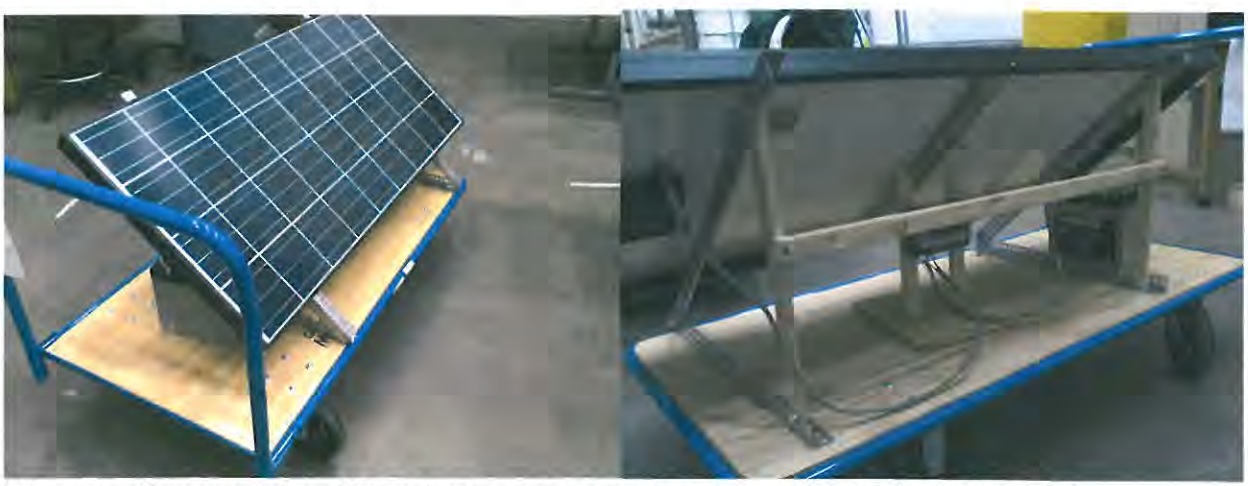


Figure 9: Constructed traditional solar energy system on mobile platform (Model 1)

Both solar panels were mounted at an angle of 35 degrees. There is, however, the ability to adjust each solar panel mounting angle to allow compensation for the earth's tilt during the change of seasons. This allows both systems to account for the earth's change and the angle of the sun if necessary.

Once the components for Model 1 were purchased and the system was constructed, the focus shifted to determining the components needed for constructing Model 2. From research, multiple ideas were generated and could theoretically work, but what could actually work in the lab and be constructed in the given time to meet the system outlined in Figure 8 was the main objective. Therefore, all the components for the Model 2 system were purchased as off-the-shelf components.

An image of the two-phase energy system prototype on a mobile platform is given in Figure 10. Additional images of the Model 2 system are provided in Appendix A. The two-phase energy system was embodied with a single solar panel, two plastic bins to store the water, 1/2" PVC piping, pump, water wheel, generator and additional auxiliary materials. The Model 2 system was also mounted on a mobile platform for easy transportation to an outdoor location for testing.

The Dankoff Slow pump 1322 was chosen for the system because it could be directly connected to the solar panel, it did not need to be submerged in the reservoir, and the total lift height (distance it could move liquid) was 280 feet at max output from the solar panel. From research the pelton water wheel was the best option for a non-submerged water application and was readily available for purchase. Two plastic bins were used as reservoirs because they were available for free and allowed easy access to the liquid stored inside. The 1/2" piping was also available for free, but a filter, check valve, manual valve, and connectors were purchased to construct the piping and to safe guard the pump when in operation. Additional auxiliary materials include bearings, rods, bushings and axels to transmit the rotational energy generated by the water wheel to the generator, the frame used to support the upper reservoir, and the water wheel enclosure. All system wiring meets electrical code standards and safety guidelines. The simple electrical load of an LED and 5VDC motor was also used to test the output of the generator.

Figure 10: Constructed two-phase energy system utilizing the rotational energy generation strategy on a mobile platform (Model 2)

A DC motor run in reverse as a DC generator was chosen to embody the rotational energy generation strategy of the two-phase energy system. Originally, an automotive alternator was chosen based on cursory research and communication with local automotive parts vendors. An AC Delco 1-wire alternator was purchased and tested for functionality. The alternator met the system voltage requirement, but required an excitation voltage to turnover which violates the goal of no chemical batteries in the system. Tests proved unsuccessful and the alternator was returned.

Three types of DC generators were purchased for the project: WindZilla generator typically used for wind energy applications, a used DC motor scavenged from a treadmill, and a new generic DC motor. The DC generators were chosen based on the ratio of RPM to output voltage using the following equation.

(Motor RPM) / (input voltage) = X [RPM/V]

The X value (ratio) was then multiplied by the desired output voltage, in this case 12 V, to get the required RPM necessary to generate 12 VDC. The lower the RPM the better. By calculation, the WindZilla generator requires 540 RPM, the DC treadmill motor requires 467 RPM, and the generic DC motor requires 600 RPM. Due to time, only two of the generators were integrated and tested with the Model 2 system.

A Bill of Materials (BOM) for the traditional system is provided in Table 2. A BOM for the two-phase energy system is provide in Table 3. Both BOMs do not factor in the cost of the mobile platforms, nor the miscellaneous construction materials that were on hand in the shop or purchased at a local hardware store (Table 4). Table 5 includes all items purchased for the project and is represented as a complete bill of materials for the project. All expenditures are listed, including those that were not anticipated in the original proposal.

Table 2: BOM for Model 1

Items	Cost
Kyocera 135 Watt KD135SX-UFBS solar panel	$306
Werken 12Volt 55aH AGM battery WKA12-55C/FR	$122.00
12 gauge wire	$8.40
Morning Star PS-15M Charge Controller	$130.00
Total Cost	$566.40

Table 3: BOM for Model 2

Items	Cost
Kyocera 135 Watt KD135SX-UFBS solar panel	$306
WindZilla Generator	$150
Treadmill Generator	$30
Turbine Wheel	$65
Dankoff Slow Pump 1322 w/ Linear Current Booster	$1,095

Fuses with Protective Housing	$15
12 gauge wire	$8.40
Total Cost	$1,669.40

Table 4: Construction Materials

Construction Items	
Hardware-bolts, nuts, screws	Wood
2 mobile platforms	Sheet Metal
Axle with mounts	Hose Filter
PVC piping	Plastic
2 Rubber maid bins	Paint-can and spray
Wooden box from plywood	PVP pipe glue

Table 5: Complete List of Bill of Purchased Materials

Materials / Supplies	**Anticipated Cost**	**Actual Costs (including shipping)**
3 Kyocera Photovoltaic Panels	$1300	$1082.45
Watt meter	$35	$0 – Not needed
Wattnode	$200	$0 – Not needed
1 Controller/Data Logger with software – Unitronics PLC	$300	$0 – Donated
2 Reservoirs	$80	$0 – Donated
1 Dankoff Pump + Linear current booster	$300	$987
1 ASCO Electrically controlled valve	$150	$157.85
Piping + accessories	$60	$45.46
3 Mechanisms for generating electricity (generator) + 1 water wheel	$300	$347.43
1 Werken Battery to compare system design + 1 ProStar Charge controller	$500	$262.95
Experimental set-up materials	$50	$95.20
3 Sensors – Day/night sensor, reservoir sensor, pump dry run cut-off sensor		$149.09
Total	$3275	$3127.43

d. Testing and Refinement

Testing that occurred on proof-of-concept prototypes was informal, and no data was collected. Only feasibility of the idea was checked, meaning reliability and repeatability of the output was monitored. Testing of the individual components was also an informal process, and no specific data was collected, except in the case of the generators purchased for the Model 2 system, as shown in Table 6. Simple tests were performed under ideal conditions to check the functionality and working conditions, to gain an understanding of how the component worked. This was helpful with troubleshooting during system integration and testing.

When testing the rotational energy generation components, a BK Precision DC power supply was used alongside a digital multimeter to measure output of both the power supply and the generators. When measuring the RPM of the generators, a handheld tachometer was used to gather data on how fast the shaft was spinning. The tachometer was also used to measure the RPM of the hand drill used to supply rotational energy to the generator to measure voltage output.

A known input was used to test two of the three purchased generators, which was a powered hand drill. The hand drill was first tested with no load attached to it and then tested while attached to each generator. Table 6 shows the results of the tests of the drill itself to establish baseline readings, and the test results of the generators. The results are in close alignment with the prior RPM/V calculations.

Table 6: Hand Drill and Generator Results

hand drill factoring rating			
low speed	400 RPM		
high speed	1400 RPM		
hand drill actual output			
low speed	460 RPM		
high speed	1532 RPM		
hand drill connected to generator		RPM	Volts (DC)
Windzilla	low speed	460	11.6
	high speed	1460	36.4
Treadmill	low speed	438	7.32
	high speed	1418	23.65

The experimental testing set-up is the two systems on mobile platforms, with the solar panels mounted at the same angle. The experimental testing conditions were determined to be two hours outside the HHS building next to the basement entrance, similarly oriented toward the sun on a sunny day. Due to possible shadows, the systems cannot be right next to each other.

Once both systems were constructed and properly wired, they were tested. Due to time limitations the systems were not tested side by side under similar conditions. Model 1 was tested first and Model 2 was tested second. Tables 7 and 8 show the output data of the systems during tests on different days. The data also is not in a comparable form. In order to truly compare the systems, data related to driving a load is needed. What can be said about the data is that both systems are working prototypes and the output that was measured is promising.

Table 7: Model 1 Output

Battery volts	Solar Amps	Data	Weather
12.3	1.9	18-Jul	cloudy
12.5	0.7	18-Jul	cloudy
13.1	8.9	25-Jul	sunny
13.2	8.5	26-Jul	sunny

Table 8: Model 2 Output

Test	Name of Motor	RPM	Volts (DC)
1	WindZilla	89	2.86
2	Treadmill	147	2.5
3	Treadmill	102	2.1
4	Windzilla	360	3.8

From the data recorded, it is apparent that electrical energy is generated by the Model 2 system. Table 8 shows the output that each generator produced and the RPM that is associated with the particular results. After the successful tests were performed on Model 2, more information was needed to understand how the upper reservoir impacted the velocity in which the liquid fell to move the generator. The parameters and influential factors listed in Table 9 were used to calculate the velocity using Bernoulli's equation [33]. Calculations are included in Appendix B.

It is known that the initial velocity of the liquid falling is greatest at the start time. At the bottom of the upper reservoir, at the initial start time, initial velocity was calculated to be approximately 8.19 ft/s. Since the reservoir is located 2.5 ft above the turbine, this means the velocity in which the liquid initially falls is approximately 15.1 ft/s. This does not mean the velocity of the liquid is constant throughout the upper reservoir draining period. The end velocity is essential zero since the liquid pressure drops as the upper reservoir losses water. This means the velocity of the water and the force in which it spins the turbine gets consistently lower as the upper reservoir drains. In a complete test trial, the liquid drained in about 1 min and 22 seconds.

Table 9: Information for calculating water force

Reservoir information	
height (in)	12.5
width (in)	13
length (in)	19
size (gal)	14
fall distance (ft)	2.5
PVC pipe size (in)	0.5
time to drain tank (min: sec)	1:22
max velocity of water at bottom of tank	
8.19	ft/s
max velocity of water as it hits turbine	
15.1	ft/s

As Model 1 was built directly from existing residential solar energy system set-ups, there was no need for refinement of the system. Model 2, however, did require refinement to result in a fully function system. The refinements are detailed in the following paragraphs.

When constructing the Model 2 system, there were many unknown situations that were encountered during construction. Following the mobile system requirement meant that the Model 2 system platform had to be designed to account for the weight and center of gravity to prevent tipping. The platform had to be balanced perfectly in order for the system to be safely moved. As system components were added the weight balance was continuously checked to ensure the system was standing perfectly vertical with no tilt to any particular side. When installing the upper reservoir to sit on top of the frame, a custom mount was made to make this possible and again the balance was checked.

When installing the turbine there was a need to keep the liquid, in this case water, contained in the system and prevent the water from leaving the system as well as splashing on the equipment. A custom enclosure was constructed to allow the liquid to flow through without leaking or splashing but also allowing a visual display of the turbine in action. The box was primed with waterproof paint and calked with sealant to prevent unwanted leaking.

The two generators tested with the Model 2 system had different shaft geometries and different physical dimensions. In order to easily switch between both generators custom mounts and couplings were made. The mounts set the generator shafts at the same height to match the height of the turbine output shaft. In order to connect either generator to the turbine output shaft, couplings designed in SolidWorks and printed in ABS plastic using the Dept. of Engineering rapid prototyping machine were created. The couplings allowed for an easy switch between generators which became useful when conducting multiple tests.

The final adjustment came with the installation of the pump, which is used to transport the liquid from the lower reservoir to the upper reservoir to complete the cycle. The pump had to be protected from the sun and potential splashing, thus another enclosure was made to fit over the pump but also allow the wires to extend out the back to be connected to the solar panel. When the first test was conducted, the pump had to be primed but there was not enough suction to have the pump self prime itself; which is what it is designed to do. With that problem, the pump would not function properly so a priming access hole was put in the PVC piping and allowed for water to be poured in. This allowed the pump to start normally and the complete the cycle.

4. Discussion

Exploring the technical challenge of sustainability as it relates to solar energy production, storage and consumption is a worthy challenge. Societies depend on energy. Exploring opportunities for generating clean, renewable energy that reduces pollutants is necessary. The replacement of chemical batteries with a fluid-mechanical "battery" for residential, renewable energy systems was explored in this project. The first research objective and the first two deliverables were met. Several strategies for energy production from a flowing liquid were conceptualized, all of which did not require the use of chemical batteries, thus showing promise for addressing research objectives 2-4 in the long term. Of the several concepts four were strongly considered and explored further, with the most viable option embodied in the two-phase energy system working prototype (Model 2).

The scale for both systems was determined to be 1/16 due to the factors of price, size, mobility, and simplicity. The larger solar panels were too large in physical size and would have complicated the mounting and mobility of the systems although no extra hardware would have been needed. The cost was also considerably higher for not much more energy output. The smaller solar panels were small enough physically to easily work this, but would have required intricate panel mounting hardware and a combiner box to make an array. While they were lower in cost, the extra hardware costs made the overall cost higher and the build process more complex. The 135 Watt solar panel that was chosen has a voltage output that is nominally 12 Volts, which meets the system voltage requirement. The physical size of the panel (59.06"x26.30"x1.8") is manageable for a mobile system. Since it is a single panel, extra hardware to make an array is not necessary and allows for more options when mounting the panel. Also, the cost was reasonable for the energy output. Consequently, the 135 Watt solar panel allowed for many of the design requirements and constraints to be met thus it was chosen for the project.

Concept development for this project was successful. The design space was explored and many alternatives or concepts were defined for the fluid-mechanical "battery". Of the many concepts the four main categories of energy generation strategies emerged: rotation, momentum, impact and return, and pressure difference. Within each category a concept was defined for further exploration. The four identified strategies provided a rich sample of the design space for the fluid-mechanical device, which lead to proof-of-concept prototypes. The proof-of-concept prototypes were successful at determining feasibility of the concepts. Within the reporting period there was only time to fully develop one conceptual design. Through refinement a viable concept was identified for the working prototype that could be implemented under the time, budget and knowledge constraints.

Embodiment of the refined viable concept for the two-phase energy system resulted in a working prototype that met the system requirements and constraints. The foremost constraint that dictated the physical prototype of the Model 2 system was the ability to fit through a standard double doorway on a mobile platform. This greatly reduced the height at which the upper reservoir could be mounted. Additionally, safety concerns as well as availability of building materials were considered during embodiment. A larger height would start to breach the safe limits of working on a ladder and accidents could happen. Needing to support the upper reservoir required a strong enough frame. A steel equipment rack that was slated for the trash was available for use and could easily support the weight of the upper reservoir. Through a combination of factors and constraints the upper reservoir was mounted 2.5 feet above the turbine to complete the working prototype on a mobile platform.

During construction of the working prototypes communication with vendors and tradesmen gave insight and knowledge on system integration, construction and testing as well as insight to foresee potential problems. Additionally, testing early and often provided insight on potential problems with the design.

Experimental tests demonstrated that the DC generator rotational energy generation strategy output was low, but feasible. There are many factors that affect the output of the generator. Energy is lost to sources of mechanical friction at many points in the system. The turbine or water wheel is connected to a shaft that is coupled to the shaft of the generator that is necessary to keep the generator away from sources of water. Along both shafts there are damping devices such as bearings that cause friction, in addition to the weight of each component which gravity is acting upon. Due to the time constraint a design of experiments was not conducted. For the rotational energy generation strategy, future tests will vary the height of upper reservoir, size of upper reservoir, pipe diameter, and generator using a design of experiments to determine the best parameters and components for generating the desired output.

Although output of the two-phase energy system is not at the desired capacity, the research performed over the reporting period shows positive results and motivates further research.

a. Research contributions

An immediate, and specific research contribution is the exploration of producing electrical energy during the night using stored energy indirectly generated from a photovoltaic energy system without chemical batteries for residential, renewable energy systems. Broad research contributions involve the exploration of the technical challenge of sustainability as it relates to solar energy production, storage and consumption, and the creation of sustainable design practices. Other research contributions include testing procedures, and cost and efficiency analyses for residential, renewable energy systems.

The results of the project will be of interest to a wide audience as renewable energy is a cross-disciplinary topic. Dissemination of research contributions, designs and project results in the form of a conference paper and presentation in one of the ASME International Design Engineering Technical Conferences (IDETC) would support reaching a broad audience with diverse interests including education, design and renewable energy. Another venue for dissemination is the VMI Annual Environment Virginia Symposium, which invites papers and presentations on energy development and efficiency and sustainability in higher education.

b. Benefits to local, state, and/or federal government

There are several benefits of the two-phase energy system. Locally, JMU and the Department of Engineering benefit from the project through education of sustainable design practices and an engineering capstone project. These benefits will be achieved through integration of the project with the JMU School of Engineering curriculum. For educational purposes, this project will be used as a design case study to teach sustainable design practices in the engineering design course sequence that all engineering majors take. Long term, this project will be a starting point for an engineering capstone project based on renewable energy production. Furthermore, this project aims to inspire young engineers to consider the pillars of sustainability throughout their careers.

Further benefits to local, state, and/or federal government that have not been realized, due to the incomplete state of the project, are the commercialization and local implementation of the phase two renewable energy technology (energy generation during the lunar cycle) and education of the public on sustainable design practices at state or national conferences.

c. Recommendations for further research

Recommendations for future research involve concept generation, embodiment and testing and refinement. Several more energy generation strategies should be explored through prototyping and feasibility tests. Once two to three feasible energy generation strategies are identified experimental tests should be performed with the Model 2 system. Tests should be performed under similar conditions to prior experimental tests, and in conjunction with the Model 1 system following the experimental testing conditions. Collected data should be compared to the results of other energy generation strategies and the typical photovoltaic energy system with batteries. Once the final set of designs for the two-phase energy system are determined, fully automating the system with a controller and appropriate instrumentation should be researched and implemented.

Further research also involves performing cost and efficiency analyses with data captured from experimental tests. A return-on-investment model should be formulated to determine the financial sustainability of the final design. The cost/benefit analysis should emulate the methods presented in [34-40]. Also, a method for efficiency comparison of the proposed two-phase energy system to a typical photovoltaic energy system with batteries, to discover similarities and differences, should be formulated using the following as a guide [41-46]. The captured data will be used to develop the return-on-investment model, and compare the efficiency of the proposed two-phase energy system to a typical photovoltaic energy system with batteries. These analyses will aid with design refinement and as a check to make sure the budget objectives are being met.

The final recommendation for further research is the creation of sustainable design practices, which builds upon all prior research. Collectively, the design, development and analysis of the two-phase energy system will lead to the definition of sustainable design practices for residential, renewable energy systems.

Potential funding sources for further research include the JMU Department of Engineering and the Environmental Protection Agency (EPA) P3 grant opportunity.

5. Conclusion

Energy consumption and generation is a major issue in the world today, which is causing people to think about their own energy needs and the sustainability of their sources of energy. The research objective of the two-phase energy system is to explore the technical challenge of sustainability as it relates to solar energy production, storage and consumption. Over the project reporting period, research and development on this issue was undertaken, which gave positive results. This project focused on meeting the goal of providing electrical energy during both day and night without the use of chemical batteries. Multiple concepts for energy production during the lunar cycle were created. Four concepts based on the energy generation strategies of rotation, momentum, impact and return, and pressure difference were chosen for further exploration to assess feasibility of the ideas. Prototypes for the rotation and momentum concepts were constructed and tested. The major weakness of renewable energy systems, the chemical battery, was replaced with a fluid-mechanical "battery" that utilizes a rotational energy generation strategy.

A 1/16 scale version of the two-phase system with the rotational energy generation strategy was constructed, as well as a traditional solar energy system with a battery for comparison. System wiring meets electrical code standards and safety guidelines. Additionally, both systems are built on mobile platforms so each can operate under similar sun conditions. Preliminary results of the rotational energy generation strategy for the lunar phase produced promising results under the constrained height conditions. Future tests will vary multiple factors to increase output of the rotational energy generation strategy. Further analysis and prototyping of the two-phase energy system will be undertaken as a two-year engineering capstone project during the 2012-2014 academic years.

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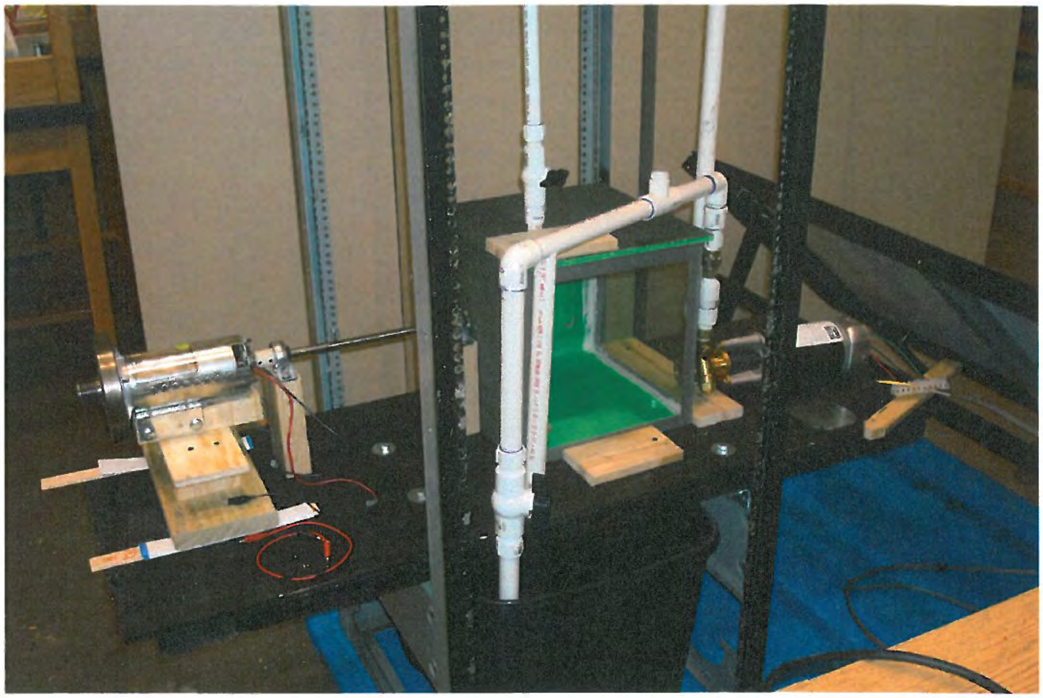
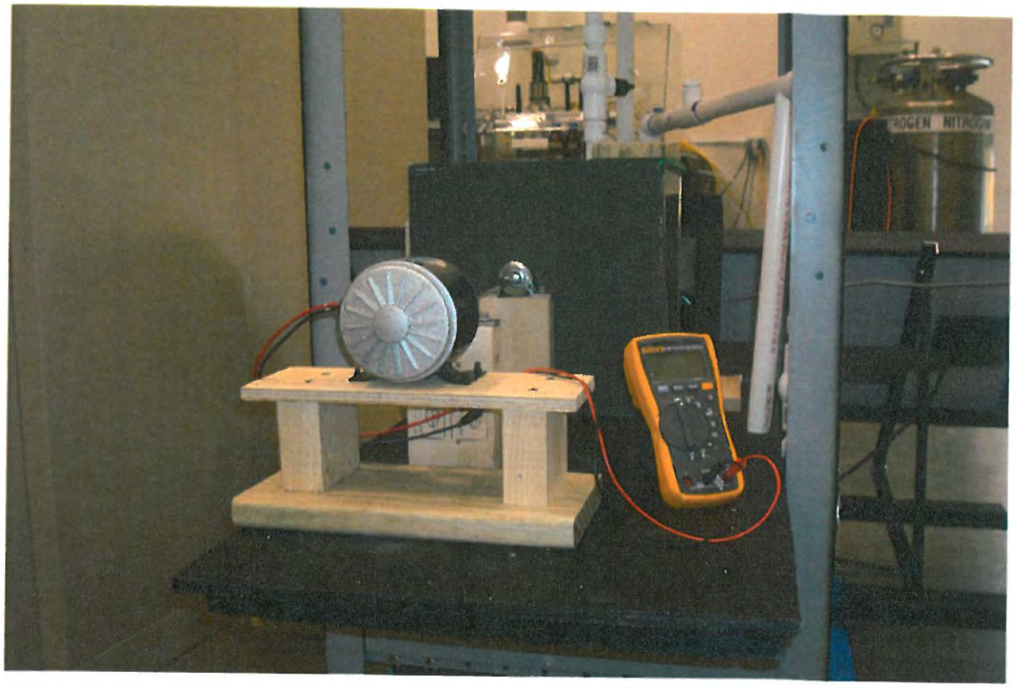
Appendix A

Additional images of the Two-phase energy system





Appendix B
Calculations of Fluid Flow

Steady, incompressible flow: $\frac{P_1}{\rho} + \frac{V_1^2}{2} + gz_1 = \frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2$

Solve for V_2 for tank
12.5 in= 1.041667 ft
Gravity = 32.2 ft/s^2

$V_2 = \sqrt{2\left(32.3\ \frac{ft}{s^2}\right)(1.041667\ ft)}$ V_2 = 8.19 ft/s –initial maximum velocity of water

Solve for V_2 to find velocity in which liquid hits turbine
12.5 in= 1.041667 ft
1.041667 ft + 2.5 ft (height)
Gravity = 32.2 ft/s^2

$V_2 = \sqrt{2\left(32.3\ \frac{ft}{s^2}\right)(3.541667\ ft)}$ V_2 = 15.1 ft/s –initial maximum velocity

A System Dynamics Analysis of the growth in Virginia's Residential Electricity Consumption trends, 1980-2010.

By

Raguram Sellakkannu

A Dissertation submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY & UNIVERSITY OF MALTA

In

Partial Fulfillment of the Requirements

for the Degree of

Master of Science

Sustainable Environmental Resources Management
&
Integrated Science and Technology

May 2013

Dedicated with love and thanks to

My Mom and Dad for their support and unchanging faith in my abilities

My sister whose sweet and timely annoyance kept me focused throughout

My kin and friends who have been my greatest source of energy

And finally

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Raguram Sellakkannnu

April, 2013

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Abstract

Residential electricity consumption in the Commonwealth of Virginia has more than doubled in three decades, between 1980 and 2010. Per capita and per household consumption rates have grown faster than many other states including New York and California. The following dissertation applies systems dynamics methodology to explore the causes of growth in Virginia's per capita and per household residential electricity consumption rates in relative contrast to New York and California over the past several decades. Major databases used in the study were accessed from the United States Energy Information Administration and the Census Bureau.

Qualitative modelling applying system dynamics principles is used to understand the general dynamics that drive residential electricity consumption across U.S households. The extent to which these dynamics prevail in Virginia is then analyzed using the state's historical data. Further comparative analysis with benchmark states of New York and California helps identify if those dynamics uniquely prevail in Virginia or are common across the benchmark states too. The study finds that a combination of economic and lifestyle factors among Virginia's residents, compounded by a low-cost high-volume 'business as usual' strategy by the state's power utility sector with negligible investments in demand side management efforts, have worked relentlessly to cause per capita and per household residential electricity consumption rates to rise in the Commonwealth during the three decades.

The results of this study are intended to support in better management of residential electricity consumption rates in the Commonwealth of Virginia. Public educational programs, Government tax credits and rebates, and stronger utility demands side management are key recommendations in the interest of addressing the issue. A successful future reduction in consumption rates will help lessen pressures on the state's economy as well as the environment.

1 INTRODUCTION

1.1 OVERVIEW

The following dissertation applies system dynamics methodology to explain why per capita and per household electricity consumption rates among Virginia's residences have grown rapidly in the past several decades and have been distinctly higher compared to most other states in the U.S. The study's results and recommendations intend to aid better management of residential electricity consumption rates[1] in the Commonwealth through suitable policy instruments. Lowering residential consumption rates will be a small step forward in managing national energy demands with associated environmental and economic benefits. This research is specific to the state of Virginia and targets its residential population. The time frame is limited from 1980 to 2010 across which the study explores underlying dynamics that influence the state's per capita and per household residential electricity consumption rates. The study also contrasts these dynamics with those of two benchmark states, namely California and New York, which show notably different trends from Virginia. Contrasting the dynamics behind Virginia's high consumption rates with those of the benchmark states and elucidating the observed discrepancies may yield useful insight to policy makers in managing the issue. Future policies are expected to acknowledge conclusions made in this study to be more effective at curbing residential electricity consumption rates in the Commonwealth.

The dissertation applies a qualitative systems modeling approach to explain the dynamics underlying Virginia's residential electricity consumption trends and contrast them with those of the benchmark states. The methodology involves constructing a qualitative systems model which will provide a holistic view of the general dynamics behind electricity consumption among U.S

[1] Note: Unless specifically mentioned, the term *'residential electricity consumption (R.El.C) rates/trends'* or *'consumption rates/trends'* used throughout the paper will collectively refer to *'per capita'* as well as *'per household' residential electricity consumption rates/trends*; it will not include 'total' electricity consumption by the residential sector.

households. The key determinants of per household and eventually per capita consumption are identified based on the model and corresponding historical trends are then analyzed specific to Virginia. Based on the analysis findings, a dynamic hypothesis is formulated justifying the rising trend in the state's per capita and per household residential electricity consumption rates. In addition, a comparative analysis with the benchmark states will help identify aspects that the Virginia Commonwealth can improve using suitable policy instruments.

The following study is important as there are significant environmental and economic impacts associated with rising electricity consumption. Electric power generation in Virginia is predominantly coal based with 47% of it generated by coal-fired power plants (Maxted, 2008). Greenhouse gas emissions from fossil fuel combustion, especially coal, make the electric power industry the most environmentally sensitive sector of the U.S economy (Repetto & Henderson, 2003) in terms of global warming. From an economic perspective, rising state electricity consumption calls for increased supply and hence more investments in electricity generation in order to meet consumer demands. According to the 2010 Virginia Energy Plan, Virginia imports nearly 30% of its electricity from out-of-state sources and a 1% reduction in State electricity imports would increase state GDP by $20 million dollars (DMME, 2010). Hence, successful reduction of Virginia's residential electricity consumption rates alongside reductions in the commercial sector will help lessen pressures on the environment and the state's economy.

1.2 BACKGROUND ON VIRGINIA'S RESIDENTIAL ELECTRICITY CONSUMPTION PATTERNS

Virginia's total electricity consumption across all sectors has increased dramatically in several respects between 1980 and 2010. According to the U.S Energy Information Administration State Energy Data System (EIA, 2012b), total end use electricity consumption in the Commonwealth of Virginia has grown by 135% from 1980 to 2010, the state's residential sector alone consistently accounting for 40% of this consumption annually. Total residential electricity consumption in

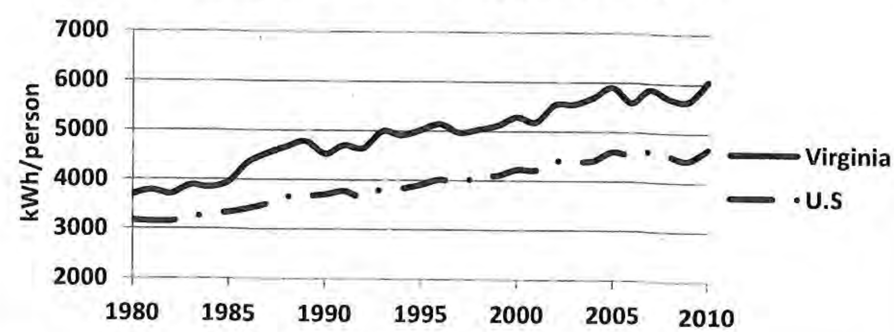
Virginia has shown a 145.5% increase during this time frame with simultaneous increases in per capita and per household residential electricity consumption (R.El.C) by 63.6% and 49.7% respectively. In addition, Virginia's per capita and per household R.El.C rates have been higher than corresponding national averages throughout the thirty years although the annual growth in R.El.C rates among the two have been fairly consistent (Figures 1.1&1.2).

1.2.1 Comparison of R.El.C trends: Virginia vs. United States

1.2.1.1 Per Capita residential electricity consumption:

As per Figure 1.1, Virginia's annual per capita residential electricity consumption has been consistently above the national average and has increased from 3,690 KWh in 1980 to 6,036 KWh in 2010[2]. This trend persists although the 63.6% increase translates into an annual growth rate of 1.6% which is only marginally higher than the nationwide annual growth rate of 1.4%.

Figure 1.1: Annual R.El.C per capita, 1980-2010.



Source: (EIA, 2012b),(CensusBureau, 2012b).

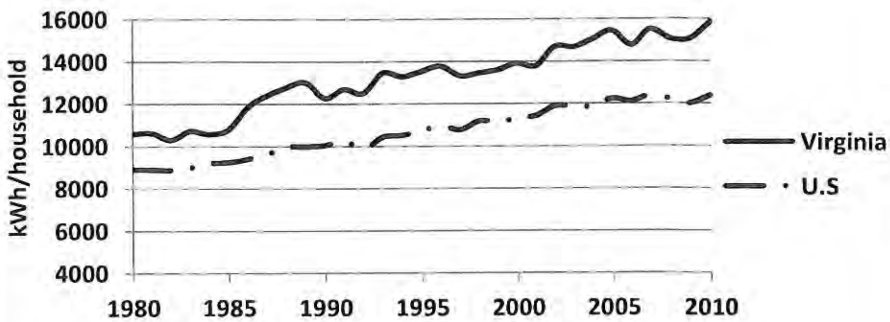
1.2.1.2 Per Household residential electricity consumption:

Virginia's per household residential electricity consumption also exhibits a similar comparison with the national trends. As per Figure 1.2, Virginia's annual figures grew from 10,591 KWh in 1980 to 15,850 KWh in 2010 equating to a 49.66% increase at 1.36% annual rate of growth. This

[2] Note that throughout this study, the term electricity and all relevant data used correspond to electricity from all fuel sources and not just fossil fuels.

is comparable to the nationwide annual growth rate of 1.22% which is representative of a 38.78% increase in per household R.El.C.

Figure 1.2: Annual R.El.C per household, 1980-2010.



Source: (EIA, 2012b),(CensusBureau, 2012b).

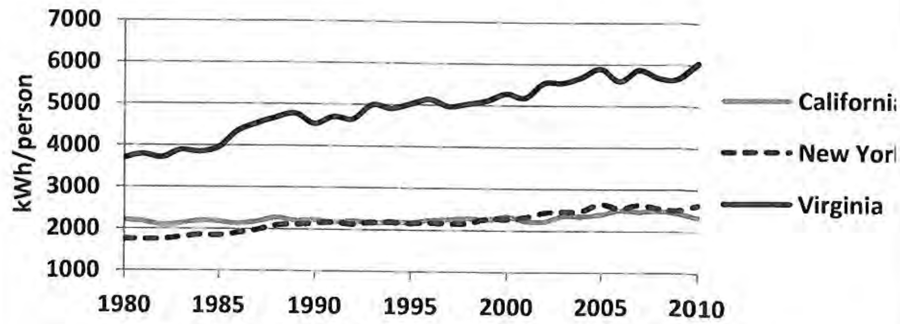
In summary, Figures 1.1&1.2 indicate that while the annual growth rates in Virginia's per capita and per household residential electricity consumption trends between 1980 and 2010 are representative of the nation as a whole, the actual consumption levels are in fact much higher than the U.S averages. Further comparison of Virginia's trends with those of benchmark states, namely California and New York, captures more intriguing discrepancies.

1.2.2 Comparison of R.El.C trends: Virginia vs. Benchmark States

During the thirty years, California and New York have exhibited higher annual total R.El.C rates compared to Virginia which are largely attributed to the much higher populations in these states (CensusBureau, 2012b). Despite this, the annual per capita and per household R.El.C rates of these two states have been much lower than Virginia's. Figures 1.3&1.4 illustrate these facts.

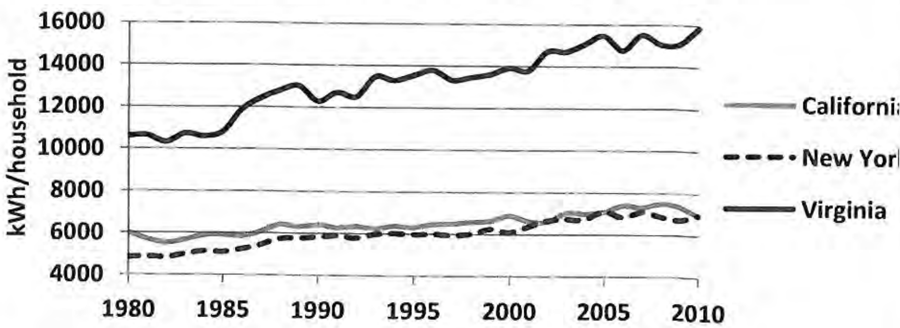
Average annual per capita and per household R.El.C levels for both California and New York have consistently been just about half of Virginia's corresponding levels between 1980 and 2010 (as seen in Figures 1.3&1.4). California's annual per capita and per household consumption levels are on average 53% and 50% lower respectively, and New York's figures are 55% and 54.6% lower respectively.

Figure 1.3: Annual R.El.C per capita, 1980-2010.



Source: (EIA, 2012b),(CensusBureau, 2012b).

Figure 1.4: Annual R.El.C per household, 1980-2010.



Source: (EIA, 2012b),(CensusBureau, 2012b).

Figures 1.3&1.4 further indicate relatively fast rising trends in Virginia's per capita and per household R.El.C rates. Although the annual growth rates in New York's R.El.C trends are just about the same as Virginia's, California on the other hand shows relatively much lower growth rates in its R.El.C trends (Refer Table 1.1). These discrepancies are important since an understanding of why Virginia's per capita and per household residential electricity consumption rates are much higher than those of California and New York may provide useful insights on how the Commonwealth can reduce these levels.

Table 1.1: Annual growth rate in per capita and per household R.El.C

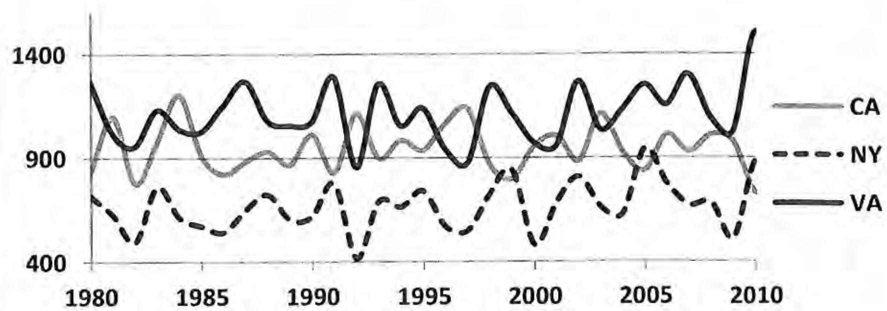
State	Annual growth rate	
	Per capita R.El.C	Per household R.El.C
Virginia	1.6%	1.4%
California	0.4%	0.9%
New York	1.4%	1.3%

Source: (EIA, 2012b),(CensusBureau, 2012b)

1.2.3 WEATHER PATTERNS, NOT A MAJOR FACTOR BEHIND VIRGINIA'S GROWING R.EL.C TRENDS

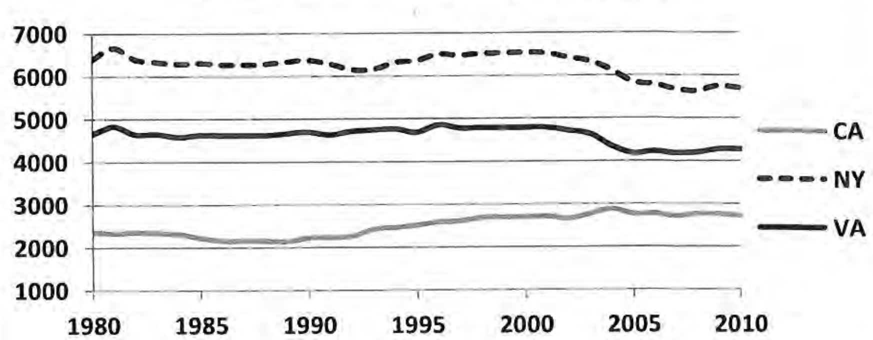
Weather patterns directly influence residential electricity consumption since extreme summers and winters impose greater electrical demands for cooling and heating respectively. Historical weather data shows that heating degree days (HDD) and cooling degree days (CDD) in Virginia have remained relatively flat between 1980 and 2010 (Figures 1.5&1.6). However during the same period, the state's per capita and per household R.El.C rates have shown dramatic increases (Figures 1.1&1.2). This indicates that changes in Virginia's weather pattern could not have been a major source of this growth even though they are a general contributor to residential electricity consumption[3].

Figure 1.5: Cooling degree days, 1980-2010.



Source: (National Climatic Data Center, 2012).

Figure 1.6: Heating degree days, 1980-2010.



Source: (National Climatic Data Center, 2012).

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[3]This fact is further justified in appendix 1.

Furthermore, Virginia enjoys a humid subtropical climate which is neither very hot nor very cold (Terwilliger, Tate, & Woodward, 1995). Despite this fact, Virginia's residents have been consuming more electricity compared to both the benchmark states. It is arguable that California has a relatively milder climate which reduces the need for excessive electricity use in residential heating and cooling. However New York, though it experiences harsher weather conditions than both Virginia and California, has also maintained low per capita and per household R.El.C levels (EIA, 2012b). These observations indicate that there are factors other than climatic conditions that have caused higher residential electricity consumption rates in Virginia. On that note, the influence of weather conditions on Virginia's R.El.C rates will not be discussed in further chapters.

1.2.4 Summary of Major Facts

Based on the comparisons thus far, notable facts regarding Virginia's per capita and per household R.El.C rates between 1980 and 2010 are summarized as follows:

1. Virginia's per capita and per household residential electricity consumption rates have been consistently higher than the national averages between 1980 and 2010.
2. The state's per capita and per household R.El.C rates have been consistently much higher than those of California and New York during the same time frame.
3. The annual growth rates in Virginia's per capita and per household R.El.C rates are noticeably higher than California (which too has exhibited an overall increase, but not as rapid an increase as Virginia).
4. Weather patterns are not a major source of growth in Virginia's R.El.C trends and do not explain discrepancies with respect to the benchmark states.

Based on the above facts, it is seemingly possible that there are opportunities to improve management of residential electricity consumption in the Commonwealth. Contrasting Virginia's dynamics against those of the benchmark states and explicating the observed discrepancies will provide valuable insights that will aid in formulating new policies aimed at managing residential electricity consumption.

1.3 Role of energy-source switching

The rising electricity consumption rates among Virginia's households are believed to be partly caused by energy-source switching; the term refers to a move made by residential consumers to switch from using non-electric appliances to those using electricity for major energy demands, usually space heating, water heating and cooking. There are several factors in the modern economy like affordability and fuel prices which can cause people to switch from traditional fuel use to electricity consumption. The study tracks the variation in 'percentage of energy use per household from electricity' over time to determine the possibility of energy-source switching[4] having occurred among households. Note, however, that the metric 'percentage of energy use per household from electricity[5]' is not an accurate indicator of energy-source switching since the metric is also influenced by the extent to which a household uses its electric and non-electric appliances; however its trend gives an idea if energy-source switching could have possibly occurred in a household. A study of Virginia's energy consumption trends indicates that the state's households may have switched energy sources considerably between 1980 and 2010; the following section supports the above fact.

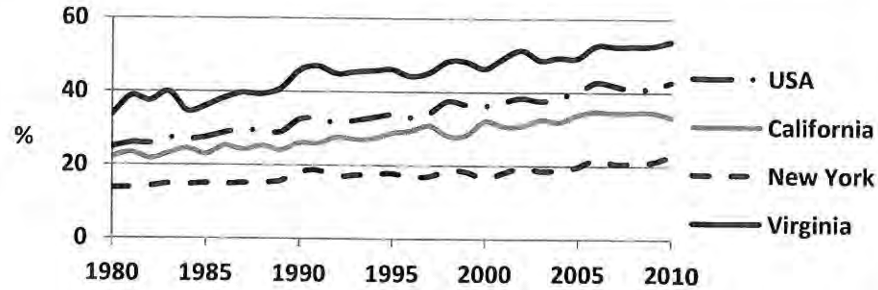
1.3.1 Energy-source switching among Virginia's households

Figure 1.7 illustrates the annual 'percentages of energy use per household from electricity' for Virginia, the two benchmark states and the U.S between 1980 and 2010. Virginia's energy use fraction from electricity is distinctly higher compared to California, New York and the U.S

[4] The term *energy-source switching* used throughout this paper will only refer to the transition from traditional fuel use towards electricity use and not vice versa.
[5] The percentage of energy use per household from electricity is calculated as the ratio of 'energy use per household' to 'electricity use per household' as a percentage.

average and is visibly rising during this period. This indicates the possibility of energy-source switching having occurred on a relatively greater scale amongst Virginia's residences.

Figure 1.7: Percentage of residential energy use per household from electricity, 1980-2010.



Source: (EIA, 2012b)

Arguably, energy-source switching may be contributing to the high consumption rates amongst Virginia's residences and eventually the discrepancies with respect to the benchmark states. It is therefore necessary to explore the dynamics behind energy-source switching in Virginia as we evaluate the sources of high per capita and per household R.El.C rates within the state.

1.4 RESEARCH AIM AND OBJECTIVES

The following dissertation aims to elucidate the dynamics behind Virginia's high per capita and per household R.El.C rates and their rapid annual growth for the selected time frame using a system dynamics approach. The principal research question is as stated:

> ***What are the sources of high per capita and per household electricity consumption in Virginia's residential sector and what has caused them to grow rapidly between 1980 and 2010, in contrast with benchmark states of California and New York?***

In order to answer this question, the remainder of this dissertation will focus on the following research objectives:

1. To develop a qualitative system dynamics model which explains the general dynamics that drive per capita and per household residential electricity consumption in U.S households.
2. To identify the major determinants of per capita and per household R.El.C and analyze their historical trends with respect to Virginia between 1980 and 2010.
3. To formulate a dynamic hypothesis that explains the trends in Virginia's per capita and per household R.El.C rates based on objectives 1&2.
4. To compare Virginia's dynamics with those of California and New York in order to identify differences that can be addressed to suppress the state's growing R.El.C rates.
5. To suggest meaningful recommendations based on the study results.

1.5 SYSTEM DYNAMICS, THE METHODOLOGY OF CHOICE

System dynamics methodology is a prominently used approach in studying problems with complex system behaviors that develop over extended periods of time. System complexity arises from feedback loops and delays which make it difficult to study such problems using conventional techniques. The methodology primarily involves defining the problem and determining the purpose of the study. This is followed by the construction of a qualitative system model using 'causal loop diagrams' in order to analyze and explain the individual dynamics that make up the problem. Based on qualitative findings, a dynamic hypothesis is formulated explaining the cause of the problem. System dynamics further uses the concept of 'stocks' and 'flows' to build a quantitative simulator model; this serves as a real-time decision making tool to policy makers and managers in developing solutions to complex problems (Sterman, 2000). However, the scope of the current dissertation is limited to quantitative system modeling and does not make use of simulation modeling concepts.

The current research problem has several characteristics that are typically found in a system dynamics case study. Most importantly, the problem is chronic as Virginia's per capita and per household R.El.C rates have grown over several decades. Multiple actors are involved including Virginia's residents and the state's power utilities. Multiple feedback dynamics exist with respect to household and utility actions; these interact with one another and give rise to complex system behaviors. The further existence of system delays and unintended consequences make the current problem worthy of a system dynamics investigation[6].

The following are some previous literature that have applied system dynamics methodology to study electricity related issues and have provided useful background knowledge applicable to the current research:

'Systems Dynamics and the Electric Power Industry', (Ford, 1997): Provides insight on the basic dynamics that are involved in functioning of power utilities and the management of utility resources, especially installed generation capacity. The study also sheds light on the famous *'utility death spiral'* which occurs as a consequence of high electricity prices and rapid expansion of generation capacity by utilities.

'Modelling household responses to energy efficiency interventions via system dynamics and survey data', (Davis & Durbach, 2010): Provides insight on the intended and unintended consequences of efficiency interventions in household energy consumption. The study further explains the *'the rebound effect'*, an unintended consequence where efficiency improvements can lead to increased energy consumption.

'System dynamics modelling for residential energy efficiency analysis and management' (Dyner, Smith, & Peña, 1995): Provides information on how subsidized electricity prices encourage higher demands further allowing utilities to increase the utilized generation capacity. By maximizing the utilized capacity, utilities are able to reduce their generation costs per unit of electricity further allowing prices to remain low.

'Investigation of pricing impact on the electrical energy consumption behavior of the household sector by a system dynamics approach' (Esmaeeli, Shakouri, & Sedighi, 2006): Explains how

[6] These dynamics are explained in subsequent chapters.

subsidized electricity prices in combination with greater family income encourage residential customers to consume more electricity.

'An Analysis of Residential Energy Intensity in Iran, A system Dynamics Approach', (Jamshidi, 2008): Explains how various factors like electricity pricing, consumption habits, pricing and efficiency of appliances, number of appliances per household, building efficiency, duration of appliance use, etc. impact residential energy demand.

Background knowledge obtained from the above literature form the basis for constructing the causal structures in chapter 2 and explaining the relevant dynamics in subsequent chapters.

1.6 DISSERTATION STRUCTURE

The subsequent chapters of the dissertation unfold according to the order of research objectives listed earlier. Chapter 2 uses the language and tools of system dynamics to formulate a ***systems-based explanation*** of the determinants of residential electricity consumption in U.S households. Chapter 3 lists out various possible scenarios under which high per capita and per household residential electricity consumption rates are bound to occur. In total, the chapter provides an understanding of how various unfavorable conditions work together to generate dynamics that lead to high per capita and per household R.El.C rates. Chapter 4 specifically explores how these dynamics have manifested in Virginia. Using the results, the chapter lays down a ***dynamic hypothesis*** which explains the cause of high per capita and per household residential electricity consumption rates and their rapid growth over time in Virginia. Chapter 5 involves a comparative analysis of Virginia's dynamics with those of the benchmark states to identify the differences that are uniquely contributing to the state's R.El.C trends. Chapter 6 concludes the dissertation with a summarized answer to the primary research question followed by meaningful recommendations aimed at improving the status quo in Virginia's residential electricity consumption trends. The dissertation does not provide a separate chapter on literature review since background knowledge gathered through the process has been used as groundwork for the various chapters.

2 SYSTEMS VIEW OF THE PROBLEM

The current chapter provides a systems view of the prevailing dynamics that drive residential electricity consumption in the U.S. The chapter walks the reader through a Causal Loop Diagram (CLD) which provides a general explanation of these dynamics; this is achieved by unfolding the relevant causal structures in a step-by-step fashion. The objective is to help the reader obtain a holistic view of the problem, gain knowledge about the various system variables, feedback loops, and interactions that impact residential electricity consumption. The analysis is organized into two sections: 1. household-level dynamics, and 2. utility-level dynamics. The former refers to those dynamics that impact residential electricity consumption from within the household. The structure includes appliance related factors like the number of appliances per household (appliance stock size), average appliance operating power (wattage), appliance run times; and other economic, social and lifestyle factors. The latter, utility level dynamics, describes the relationship between residential electricity demand and how utilities address pricing, generation capacity, and demand side management[7] strategies. The findings of the analysis will help explain Virginia's per capita and per household R.El.C trends in later chapters of the dissertation.

Note that the household and utility level dynamics, to be explained in sections 2.1 and 2.2 respectively, focus only on 'per household' residential electricity consumption. The explanation behind how these dynamics influence 'per capita' residential electricity consumption is accounted for towards the end of the chapter. This will lay the groundwork for subsequent chapters through which the principal research goal of explaining Virginia's per capita R.El.C trends is addressed.

[7] Demand side management refers to strategies employed by utility companies in order to manage electricity consumption on the consumer side of the power grid (Mohsenian-Rad et al., 2010).

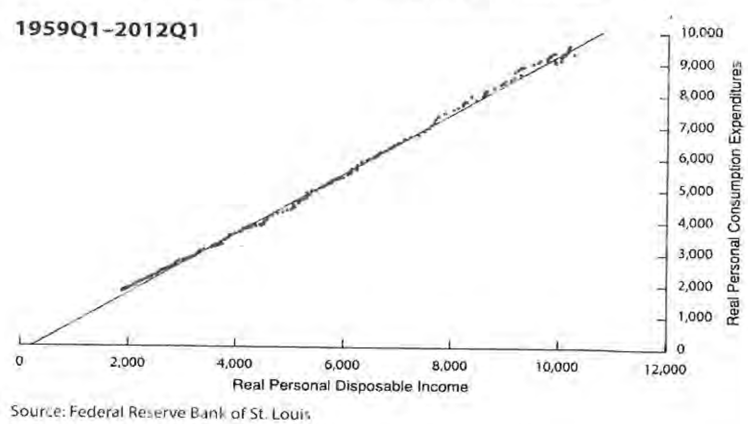
2.1 HOUSEHOLD LEVEL DYNAMICS

It is ultimately the type and extent of electrical appliance use for various residential services that determines the electricity consumption rate in a household. There are several forces that affect household-level decisions and actions which influence its electricity consumption patterns. These forces emerge out of interactions between economic factors like household income, social aspects like family lifestyle, household size, spending attitudes, and other factors such as technological advancements and climate. These interactions affect the net household electrical demand by influencing appliance related factors such as the number of appliances per household (appliance stock), their operating power (wattage), and their extent of use (run time). The discussions in this section will allow the reader to understand the interaction between these factors and the resulting impact on per household electricity consumption.

2.1.1 HOUSEHOLD INCOME: A CENTRAL FACTOR AFFECTING ELECTRICITY CONSUMPTION HABITS

A household's income level influences several factors including appliance stock, residential square footage, household power consumption attitude and also its ability to invest in home efficiency improvements or new energy efficient appliances. Consumer spending is strongly determined by the buying power concealed within paychecks, commonly referred by economists as the real personal disposable income. Figure 2.1 represents the close correlation between real personal disposable income and real personal consumption expenditures in the United States from 1959 to 2012 (Cunningham, 2012). Hence the absolute real disposable income of a household is positively associated with its spending capacity which therefore determines its ability to purchase electrical home appliances, or to make home renovations for efficiency gains, or to replace old inefficient appliances.

Figure 2.1: Correlation between real personal disposable income and real personal consumption expenditures.



Source: (Cunningham, 2012)

The study uses the term household discretionary income which is a more specific economic indicator compared to real personal disposable income. A household's discretionary income is defined as the income which is left after spending on essentials like food, clothing, shelter, taxes and utility bills. In other words it refers to the money available to the household to be spent on luxury goods, home expansion, non-essentials, etc. The term more specifically indicates a household's affluence and its influential role as an R.El.C aggressor within the household level dynamics is discussed in subsequent sections to follow.

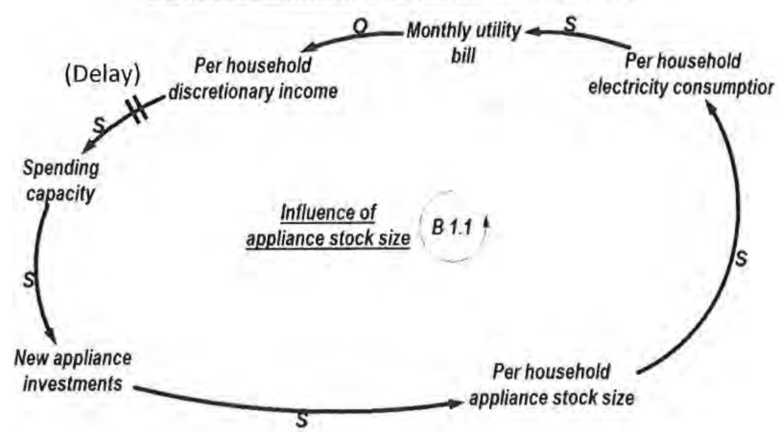
Before proceeding further, the study underlines an important delay dynamic with respect to discretionary income which is common among all the household level causal loops to follow. An increase in utility bills due to high household R.El.C[8] causes discretionary income to decline; however, it takes time for the discretionary income to drop below a certain threshold beyond which economic hardships manifest and the household's spending capacity decreases. Hence there exists a delay wherein it takes considerable time for households to realize the impact on spending capacity, identify the cause of economic hardship (high household R.El.C in this case) and take corrective action. This delay is longer in more affluent families due to their greater capacity to absorb high utility bills. On the other hand, when utility bills are low and households

[8] The term 'Household R.El.C' refers to 'per household R.El.C'.

are left with more discretionary income, it normally takes time for the savings and hence spending capacity to build up to an extent before further investments in home appliances, new larger homes or efficiency upgrades can be made. This delay is indicated in the causal loop diagrams that follow and will not be elaborated upon in further discussions. Sections 2.1.2 to 2.1.8 describe income-driven factors which influence residential electricity consumption among households.

2.1.2 INFLUENCE OF APPLIANCE STOCK SIZE

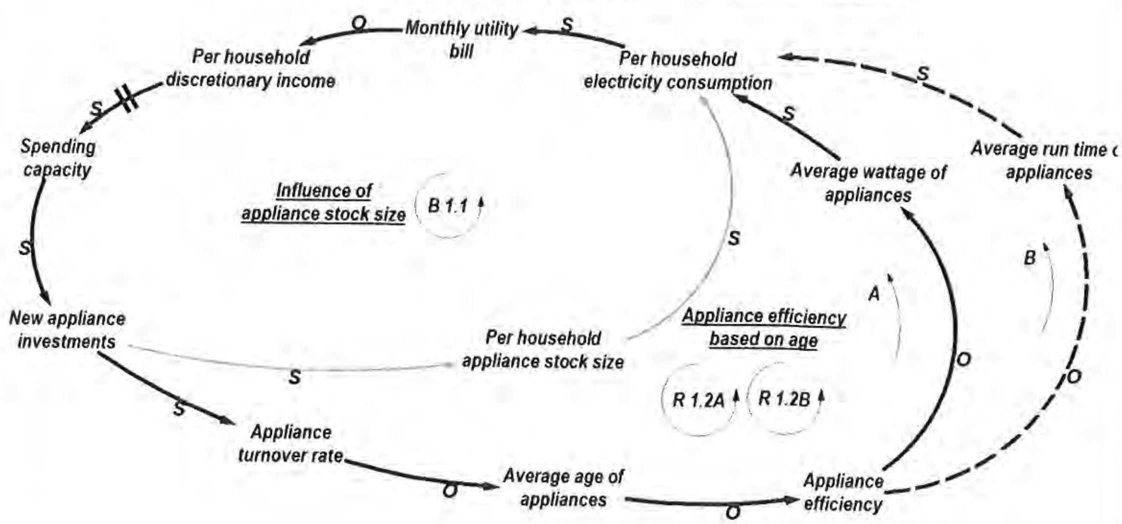
Figure 2.2 : Influence of appliance stock size



Since R.El.C is determined by the operating powers and run times of individual appliances, a large appliance stock will add to the electrical load of a household. Further, a larger stock would also imply more plugged-in appliances thereby increasing phantom loads. A larger electrical load combined with unwanted phantom loads will inevitably drive up the per household electricity consumption. Families with higher discretionary incomes are more likely to invest in new appliances for luxury and pile up their stock of appliances compared to low income families. According to loop B1.1 in Figure 2.2, a household with a large appliance stock will see higher consumption and utility bills which can choke the family's discretionary income and further appliance purchase capacity. In a household with a relatively small appliance stock, the consumption and utility bills will likely be lower. The money saved will add to the discretionary income and improve the household's chances of purchasing more appliances. This explains the balancing nature of the loop.

2.1.3 INFLUENCE OF APPLIANCE EFFICIENCY (BASED ON AGE)

Figure 2.3 : Influence of appliance efficiency (based on age)



Loops R1.2A&B in Figure 2.3 are reinforcing feedback loops which describe how higher efficiency levels related to a younger stock of appliances in the household influence household R.El.C and cause the resulting savings to further reinforce the loop. Appliance efficiency levels are usually negatively associated with age since components begin to malfunction as appliances get older. Studies show that running an older model refrigerator can consume up to 66% more electricity than a new ENERGY STAR certified refrigerator (Ashley-Chicot Electric Cooperative). Newer appliances are advantageous not just for their minimized inefficiency but also because they possess more efficient latest technologies as explained below:

1. New efficient appliances are built to work with relatively lower operating power (wattage) making them cheaper to operate in the long run (R1.2A). Appliances with low operating

power consume fewer KW of electricity over a fixed run time compared to those with higher operating powers.

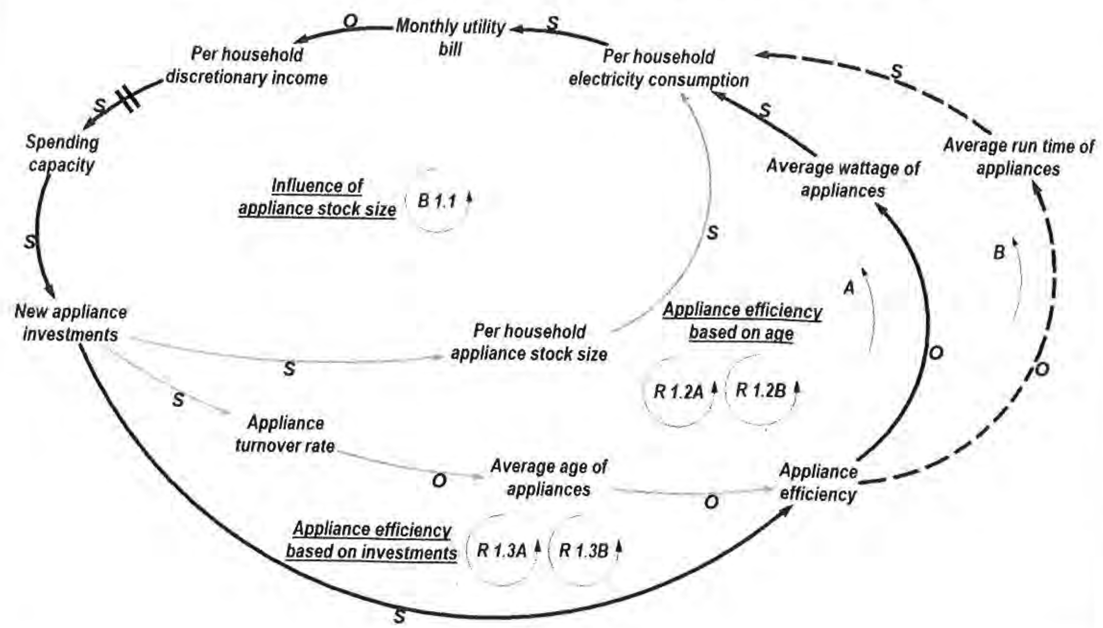
2. Newer appliances are typically built to reduce phantom loads which refer to the power consumed by plugged-in electronic devices or appliances even when they are switched off or in standby mode (Rusk, Mahfouz, & Jones, 2011). To avoid phantom loads, efficient devices enter a low power state during standby mode thereby reducing the actual appliance run time sharply (R1.2B).

Households must invest liberally in order to maintain a decent appliance turnover rate. Relatively more affluent families are likely to replace old, outdated electrical appliances more frequently with newer efficient technology compared to less affluent ones. The resulting savings seen by such families will add to their discretionary income and reinforce further spending capacity on newer appliances. Turnover rates are likely to be low among lower-income families due to reduced spending capacity; the inefficiencies from ageing appliances will reflect in the utility bills which in turn will further cramp the family's discretionary income and spending capacity. This explains the reinforcing behavior of the loop.

2.1.4 INFLUENCE OF APPLIANCE EFFICIENCY (BASED ON INVESTMENTS)

The efficiency of appliances purchased by consumers depends on the amount of money they decide to invest. Although the entire appliance market has grown in electrical efficiency over the past three decades, not all appliances are equally priced and equally efficient. In today's market, more efficient appliances cost more. For example, the more efficient 'ENERGY STAR' labeled consumer appliances and electronics carry a higher price quote compared to less efficient models. However, the operating cost of such efficient appliances is much lower compared to their counterparts as these utilize lesser electricity in the long run; this can be attributed to their lower wattage (R1.3A) and lower absolute run time (R1.3B). This makes the life cycle cost, which is the purchase price and operating cost combined, of an 'ENERGY STAR' labeled appliance typically lower than a less efficient model (I.F.E, 2010). Investing up front in highly efficient appliances can also help reduce the need for frequent turnover as discussed in the previous section.

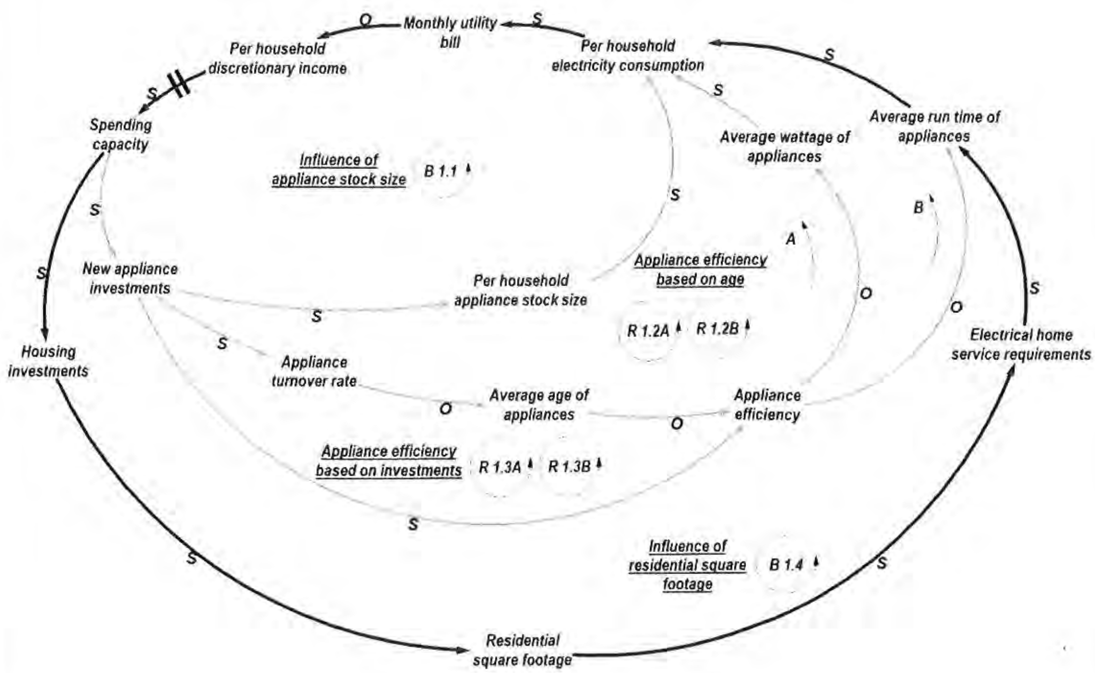
Figure 2.4 : Influence of appliance efficiency (based on investments)



Consumers must choose wisely to invest in efficiency while purchasing appliances in spite of the high initial costs involved as it will pay off in the long run. Affluent households are more likely to make such wise investments that will result in future electricity savings, reduced utility bills and a subsequent increase in the household discretionary income. On the other hand, less affluent households may find it difficult to put up with high initial costs and may opt for cheaper less efficient appliances that are more electrically intensive. This will result in an increase in consumption and higher utility bills further suppressing the spending capacity of the household due to a lowering in discretionary income. This explains the reinforcing nature of loops R1.3A&B.

2.1.5 INFLUENCE OF RESIDENTIAL SQUARE FOOTAGE

Figure 2.5 : Influence of residential square footage

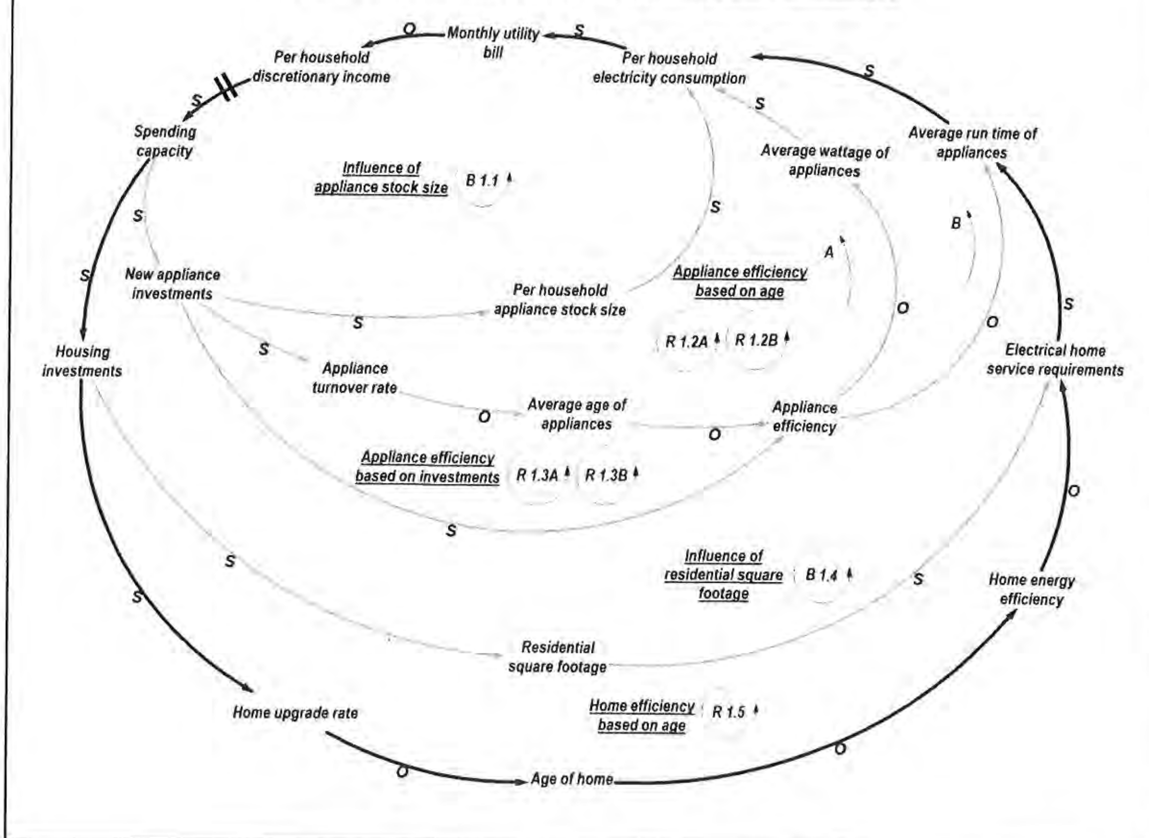


Loop B1.4 is a balancing feedback loop in which residential square footage is the fundamental variable. The square footage of a household's residence is prominently determined by the family's discretionary income. More affluent families tend to live in larger homes which require more space heating, cooling and lighting as they are more spacious. These are collectively referred as electrical home services requirements in Figure 2.5. The respective appliances such as heat pumps, air conditioners, electric lamps, etc. are likely to be run for longer durations in larger homes. Eventually, the electricity consumption per household is positively associated to the residential square footage.

The loop is balancing since variations in the monthly utility bills are accompanied by a balancing effect on the household's discretionary income and eventually it's spending capacity. In the case of larger residences, the resulting higher utility bills will lower the discretionary income and choke the spending capacity of the household making it difficult for further home expansion or even forcing the family to move to a smaller home. Likewise, families living in smaller residences are likely to see lower utility bills thus leaving them with more discretionary income and a better chance to expand their homes.

2.1.6 INFLUENCE OF HOME EFFICIENCY (BASED ON AGE)

Figure 2.6 : Influence of home efficiency (based on age)



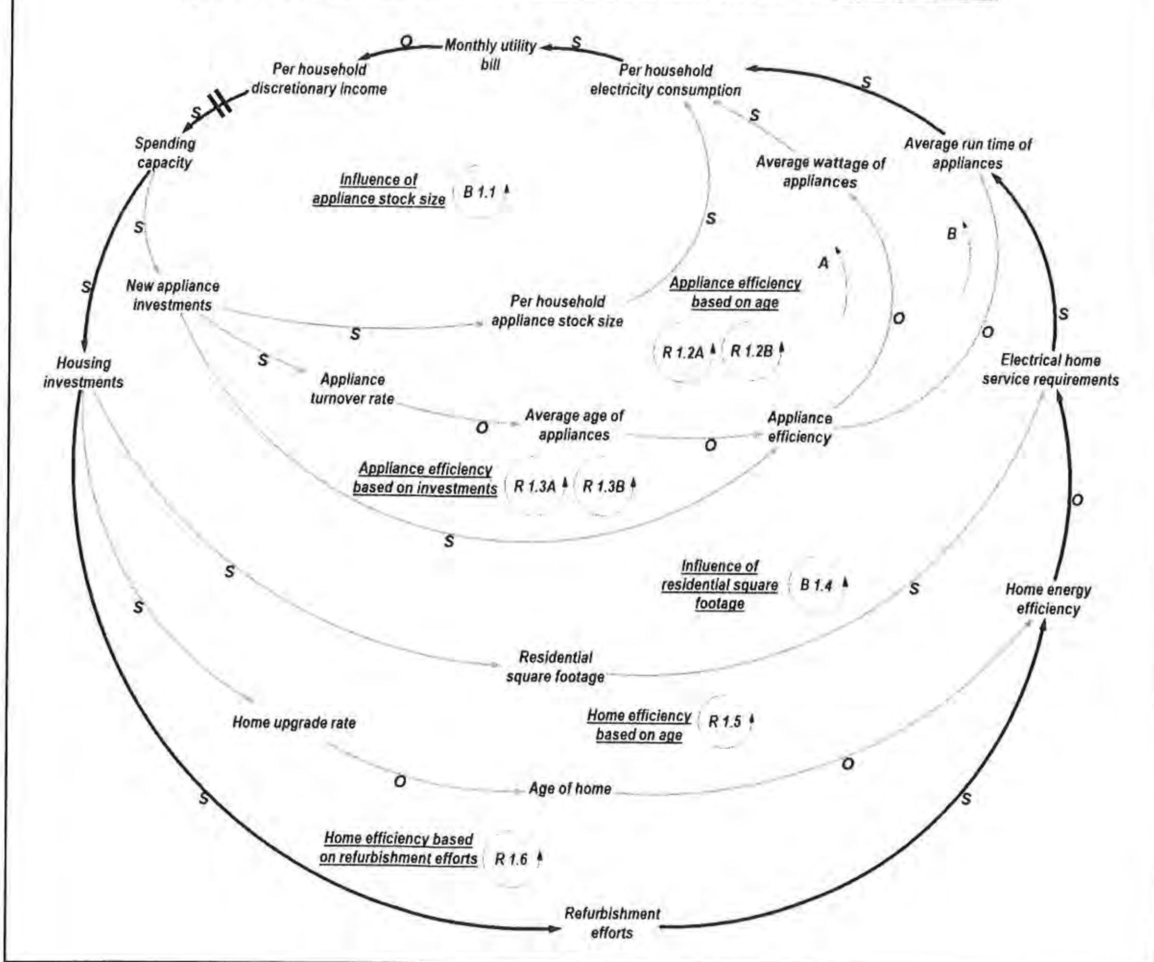
Age is an important indicator of electrical inefficiency in housing units. As housing-units age, they tend to leak conditioned air from within due to ruptured sealing and inadequate thermal insulations. During winter for instance, hot inside air leaks out through holes or cracks and is replaced by colder ambient air. This unwanted leakage is known as infiltration. Apart from infiltration, heat can also be lost in the form of conduction, convection and radiation losses through walls, windows, ceilings, floors and doors (Randolph & Masters, 2008). Such inefficiencies will automatically raise the need for residential electrical services, especially home heating, cooling and water heating, as the appliances will have to work harder to overcome the heat losses due to home inefficiencies. This will eventually drive up per household R.El.C. The above mentioned losses are relatively lower in newly built homes as they usually comply with efficiency standards implemented in the U.S Department of Energy's Building Energy Codes Program. Upgrading to newly built and efficient homes at reasonable intervals can therefore help reduce per household R.El.C.

Affluent families are more likely to upgrade to newer homes as they are financially capable. Monthly electricity savings will add to their discretionary income and further reinforce their capacity for future home upgrades. Low-income families on the other hand may rarely or almost never upgrade their homes due to financial constraints; the inefficiencies associated with ageing homes will further constrain their spending capacity through greater utility bills. This explains the reinforcing behavior of loop R1.5 in Figure 2.6.

2.1.7 INFLUENCE OF HOME EFFICIENCY (BASED ON REFURBISHMENT EFFORTS)

Households that like to live in vintage homes for their historic value, or are unable to upgrade to newer homes due to financial constraints can consider home refurbishments to improve energy efficiency. Energy inefficiencies due to infiltration and heat losses can be significantly reduced through suitable building refurbishments; these include investing in efficiency upgrades like thermal insulations, double pane windows, etc. Such technologies allow home appliances to run more efficiently as unwanted run times for heating or cooling applications are reduced. Furthermore, improving home efficiency through refurbishment efforts also lessens the need to upgrade to a more efficient home.

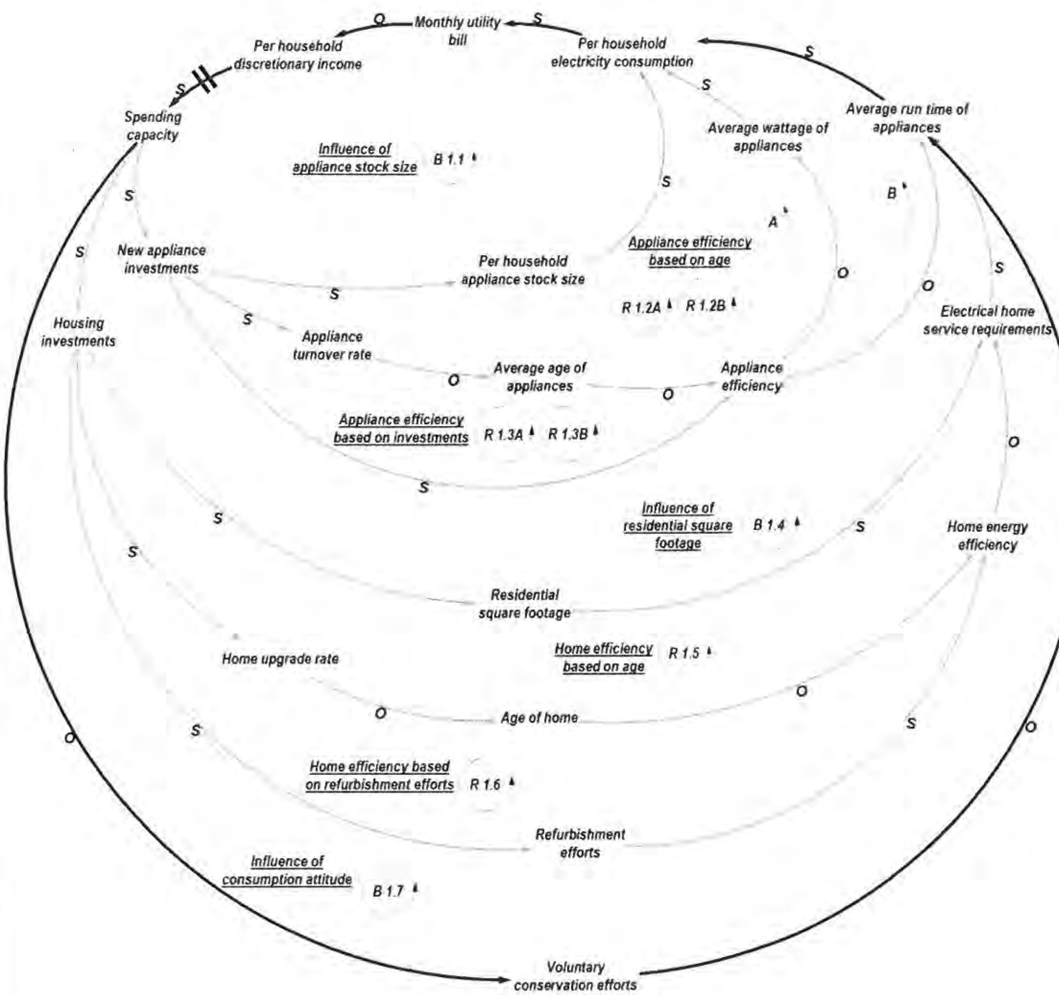
Figure 2.7 : Influence of home efficiency (based on refurbishment efforts)



According to reinforcing loop R1.6, investing in home refurbishments helps realize electricity savings and eventually increase household discretionary income due to lower utility bills. This reinforces household spending capacity and allows for further refurbishment investments (Figure 2.7). Neglecting residential energy inefficiencies and failure to invest in home refurbishment will only increase per household R.El.C and monthly utility bills. This in turn will choke the household's discretionary income and future capacity to invest in refurbishment efforts.

2.1.8 CONSUMPTION ATTITUDE, A FUNCTION OF DISCRETIONARY INCOME

Figure 2.8 : Influence of consumption attitude



Balancing loop B1.7 in Figure 2.8 illustrates the influence of a family's discretionary income on its diligence toward electricity conservation. In a family whose members are careless about electricity consumption, the run times of various appliances are automatically high due to unnecessary use. The resulting increased utility bills will tend to choke the family's discretionary income making it necessary for its members to reconsider their consumption attitudes and be more cautious; this promotes voluntary electricity conservation measures. However, there is always a chance that savings which result from conservation measures will ease the strain on the family's spending capacity by reinforcing its discretionary income and reduce its attention towards voluntary conservation measures. This explains the balancing or goal seeking dynamics of the loop.

2.1.9 EXOGENOUS FACTORS AFFECTING RESIDENTIAL ELECTRICITY CONSUMPTION

Apart from the variables in Figure 2.8, there are several others that influence household R.El.C and are treated exogenous to the problem. These include the number of heating/cooling degree days, household size (# members per household), market pricing of appliances, house price index, market pricing of building refurbishment materials and technological advancements. The impacts of these variables on per household residential electricity consumption are explained in the following sections.

2.1.9.1 Heating/cooling degree days:

Heating degree days (HDD) and cooling degree days (CDD)[9] provide a measure of the climatic intensity of a given location with respect to temperature. For a given electricity-based heating and cooling system, the electricity required for home heating is proportional to the annual HDD while that required for home cooling is proportional to the annual CDD (Thevenard, 2011). This is because high figures in annual HDD or CDD for a particular location raises the need for residential heating or cooling services respectively as HVAC units would have to run for longer durations to heat or cool the home. This results in increased per household R.El.C. Conversely, lower annual HDD or CDD will reduce home heating or cooling needs and allow for reduced per household R.El.C.

[9] The HDD and CDD for a particular year are calculated as the summation of the differences between the daily average temperature and the base temperature for an entire year; the base temperature refers to the temperature level that is adequate for human comfort. Daily average temperatures in case of HDD calculations are usually lower than the base temperature and higher in case of CDD calculations.

2.1.9.2 **Household size (# household members):**

Household size influences household R.El.C in the following ways:

1. The total demand for electrical home services like water heating, electric cooking, laundry and lighting increases significantly with household size since each household member must satisfy his/her personal needs. This in turn would increase total electricity consumption of the household.
2. More people in a household typically require a larger stock of appliances especially due to personal electronic gadgets like cell phones, tablets, laptops, etc. Hence the size of a household affects R.El.C per household by influencing its appliance stock.
3. Household size also indirectly affects per household R.El.C. The number of members in a household has a direct impact on its total expenditure for basic needs such as food, shelter, clothing, utilities, etc. In a larger household, although the per capita expenditure for basic needs including electricity consumption may reduce due to sharing of certain services (e.g. home heating, lighting, etc.), the net expenditure of the entire household is usually higher (Cutright, 1971). Discretionary income will eventually reduce thereby affecting the way future household decisions are made; for instance, investments in efficiency upgrades may not be seen as an immediate priority and this will impact electricity consumption rates. The opposite is the case for smaller households.

2.1.9.3 **Market pricing of appliances:**

Market diffusion rates of home appliances and electronics are affected by how they are priced. Cheaper and affordable prices can boost diffusion rates and hence result in appliances accumulating across consumer residences. Larger appliance stocks among households will eventually drive up per household R.El.C as explained in Section 2.1.2. Note that market pricing also affects the diffusion rates of appliances that are certified for higher efficiency. High pricing of efficient appliances could slow down their penetration especially into less affluent households. On the other hand, affordable pricing of such appliances can encourage consumers to invest and improve efficiency levels among their households. Hence, appliance prices indirectly affect household R.El.C by influencing efficiency levels and appliance stock size among households.

2.1.9.4 **Average prices of homes:**

Affordable sale or rental prices of homes will provide a better chance for households living in older homes to upgrade to newer and more efficient households. High prices on the other hand would make it difficult for less affluent households to make such an upgrade. Furthermore, affordable prices can also result in more affluent households willing to adopt larger sized homes. As explained in Section 2.1.5, residential square footage in turn is proportional to household residential electricity consumption. Therefore, sale or rental prices of homes indirectly influence per household R.El.C.

2.1.9.5 **Market pricing of building refurbishment materials:**

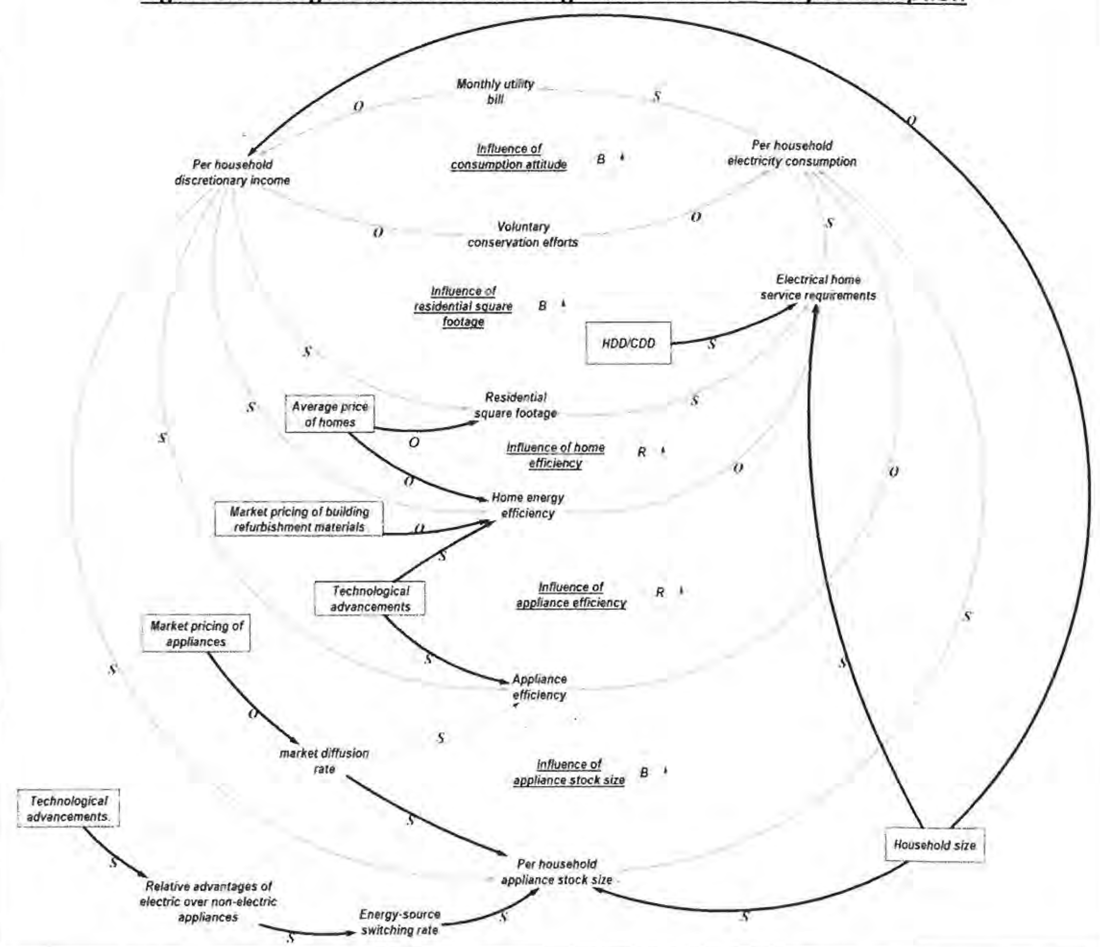
Affordable refurbishment materials like thermal insulations, double pane windows, etc. will encourage households to make necessary investments to improve home efficiency levels. High prices on the other hand could slow down their market diffusion rates and indirectly affect residential electricity consumption rates among households.

2.1.9.6 **Technological advancements:**

Ever since 1980, electrical appliances have gained significant improvements in efficiency standards while their prices to consumers have in general decreased (Yost, 2010). New building materials have been developed that are more energy efficient; these include thermal insulations, double pane windows, etc. These improvements can be attributed to continual investments in research and technological development by the appliances and building industries. As discussed earlier, efficiency improvements are necessary to dampen household R.El.C and continual technological advancements are necessary for future improvements in efficiency standards.

Besides efficiency improvements, technological advancements have also improved the relative advantages of electrical appliances in several respects and made them preferable over their non-electrical counterparts. Advantages include - (i) relative cost effectiveness of electrical equipment with respect to purchase, operating and maintenance costs, (ii) and operating convenience i.e. the ease of use to consumers. Although they do have their cons, these relative advantages are possible reasons that could cause people to switch from using conventional or even renewable-based appliances like gas stoves, solar heaters, etc. towards using electrical appliances; this is otherwise referred to as energy-source switching as discussed in chapter 1.

Figure 2.9 : Exogenous factors affecting residential electricity consumption



2.2 UTILITY LEVEL DYNAMICS & THEIR INTERACTIONS WITH RESIDENTIAL ELECTRICITY CONSUMPTION

The dynamics discussed thus far form the basis for electricity consumption patterns within individual households. The current section will focus on utility level dynamics which refer to the dynamics in which power utilities have a role to play and which go on to affect residential electricity consumption. The causal-loop diagrams in this section will explain the utility's actions in response to total residential electricity demand. Such actions may include (i) adjusting utility prices in response to variations in consumer electricity demand, (ii) adjusting prices to pay for capacity expansion, and (iii) promoting demand side management strategies to reduce consumer demand. The influence of these actions on residential electricity consumption and subsequent feedbacks are illustrated in the following discussions.

Figure 2.10 : Simplified household level CLD

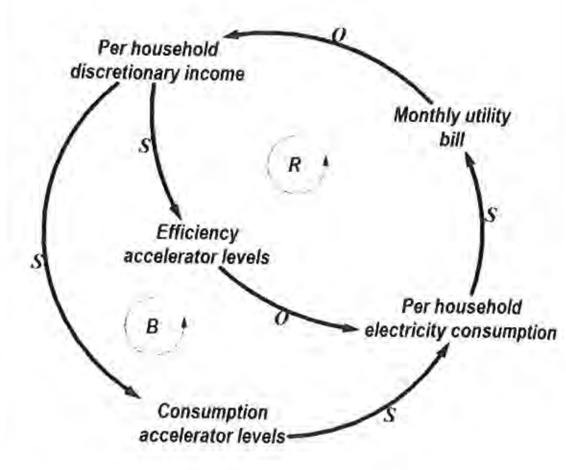


Fig.2.10 represents a simplified version of the household-level causal loop diagram. It is a condensed representation of the household-level dynamics that drive residential electricity consumption and is used as the basis to show how they are influenced by utility-level dynamics. Exogenous variables are not shown since their states are not affected by utility level dynamics. Also, all endogenous variables that lie between 'per household discretionary income' and 'per household electricity consumption' in Figure 2.9 are aggregated under two variables; these are

consumption accelerator levels and ***efficiency accelerator levels*** according to the role they play within the household level dynamics. Greater levels of consumption accelerators will drive up R.El.C rates while greater levels of efficiency accelerators will suppress R.El.C rates. Table 2.1 lists the various endogenous household level variables categorized under residential consumption accelerators and efficiency accelerators. The balancing loop (B) in Figure 2.10 represents how higher discretionary income drives up R.El.C rates by intensifying consumption accelerator variables like appliance stock size, appliance run time, etc. and how the resulting utility bills reduce household discretionary income. The reinforcing loop (R) represents how higher discretionary income will help dampen R.El.C rates when invested in efficiency upgrades and how the resulting savings will reinforce the household's discretionary income.

Table 2.1 : Categorized list of endogenous household level determinants

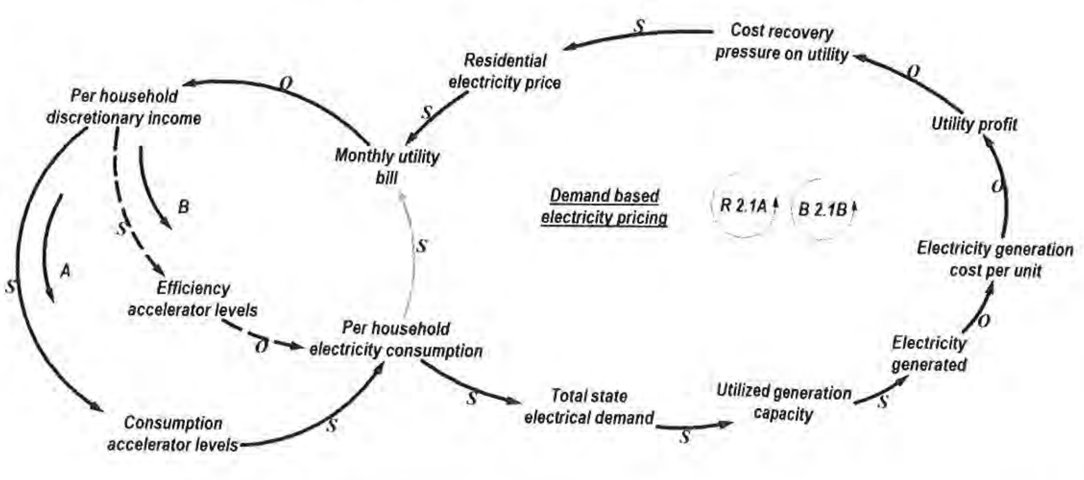
Consumption accelerators	**Efficiency accelerators**
Positively associated factors w.r.t consumption	Negatively associated factors w.r.t consumption
1. Appliance stock size per household 2. Average wattage of appliances 3. Average run time of appliances 4. Average age of appliances 5. Residential square footage 6. Age of home 7. Electrical home service requirements	1. Appliance efficiency 2. Appliance turnover rate 3. Home upgrade rate 4. Home energy efficiency 5. Refurbishment efforts 6. Voluntary conservation efforts

The various utility level causal-loop diagrams (CLDs) to follow are constructed using the simplified CLD shown in Figure 2.10 as the foundation.

2.2.1 DEMAND BASED ELECTRICITY PRICING

Figure 2.11 illustrates the possible variation in residential electricity prices in response to changes in consumer demand and how this impacts household residential electricity consumption. Loop R2.1A represents feedback with respect to consumption accelerators while loop B2.1B represents feedback with respect to efficiency accelerators. Based on commodity system dynamics, high consumer demand is vital for increased producer profits. Higher demands encourage producers to increase their production volume which in turn will lower the unit production cost since total production costs are distributed across a larger production volume; production volume is increased either by maximizing utilization of existing production facilities or by building new facilities or by a combination of both. Lower production cost per unit in turn results in a greater profit margin for the producer (Sawin et al., 2003). The same applies to power utilities. A high total residential electricity demand in the state will prompt utilities to increase utilization of their existing plants to generate more electricity; the result is a greater profit margin per unit of electricity sold due to lower generation costs per unit (Figure 2.11). Greater profits will reduce utility pressures to recover its operating costs and investments; this will hence allow utilities to sell electricity at modest or even lower prices to its consumers.

Figure 2.11 : Demand based electricity pricing



Under a low electricity pricing scenario, households will enjoy lower utility bills and increased discretionary incomes which are likely to be followed by increases in the levels of residential consumption accelerators (loop R2.1A). The resulting increase in R.El.C rates across households will increase the state's residential electricity demand and will allow for further lower electricity prices; this explains the reinforcing behavior of the loop. In case of high electricity prices, households are more likely to take measures to curb electricity consumption hence reducing the total demand. This will increase unit cost of electricity production due to reduced capacity utilization, hence causing utilities to face lower profit margins. Utilities will therefore be pressured to recover lost revenue by requesting the State Commission to raise electricity prices to its customers. Without other checks and balances, utilities will eventually enter a vicious loop commonly known as 'the utility death spiral' in which increasing the utility prices will only lower further demand and create the need for another price hike (Ford, 1997). This makes the reinforcing loop R2.1A crucial to the study. Also note that among highly affluent households, high electricity prices may not pose an economic pressure. This is referred to as low price elasticity of demand and in such case, household electricity consumption may continue to rise up to a threshold beyond which the economic pressures are felt.

As per balancing loop B2.1B, low electricity prices will leave households with higher discretionary incomes that may be invested in efficiency upgrades. Although this may help lessen unnecessary consumption, such efficiency improvements among households may not be significant enough to actually lower the net demand to utilities and cause an increase in electricity prices. This is because low prices boost consumption accelerator levels simultaneously (as per loop R1.2A) and generally leading to greater consumer demand (Ford, 1997). In summary, the feedback due to efficiency accelerators (loop B2.1B) is considered relatively weaker than that due to consumption accelerators (loop R1.2A), i.e. total state electricity demand has a net negative association with electricity prices and the reinforcing behavior due to consumption accelerators is relatively more dominant. Similar theory applies to further discussions as necessary.

2.2.2 ASSET BASED (INSTALLED UTILITY CAPACITY) ELECTRICITY PRICING

Figure 2.12 : Asset based electricity pricing

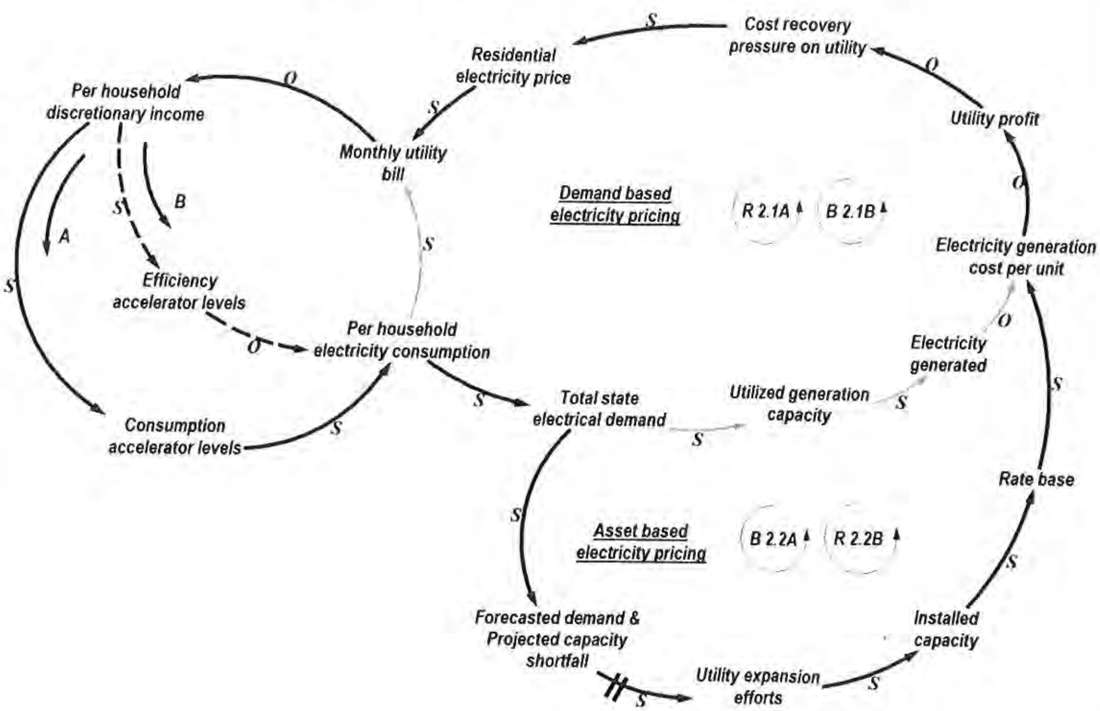


Fig.2.12 illustrates pricing variations in response to utility expansion efforts and the resulting impact on household R.El.C rates. Loops B2.2A & R2.2B represent feedback dynamics with respect to consumption and efficiency accelerator levels respectively with the former being more dominant of the two. Power utilities in the U.S periodically forecast electricity demands five years out in order to determine if they have the necessary generation capacity to meet those demands. In the case of a high projected capacity shortfall which is likely to occur with steep growths in total state electricity demand, utilities may have to expand by installing new generation capacity. This will increase the power utility's rate base which refers to the total value of a utility's assets and is considered a key factor in determining the electricity price to consumers (Scott, 2003). A larger rate base would imply larger electricity generation costs per unit and higher pricing to customers since investments in new capacity installations will have to be

recovered. When demand remains such that utilities do not have to expand capacity, electricity prices to customers can remain modest or low depending upon generation costs. Note that installing new capacity is a long term process and hence a delay exists before prices actually rise up in response to capacity expansions.

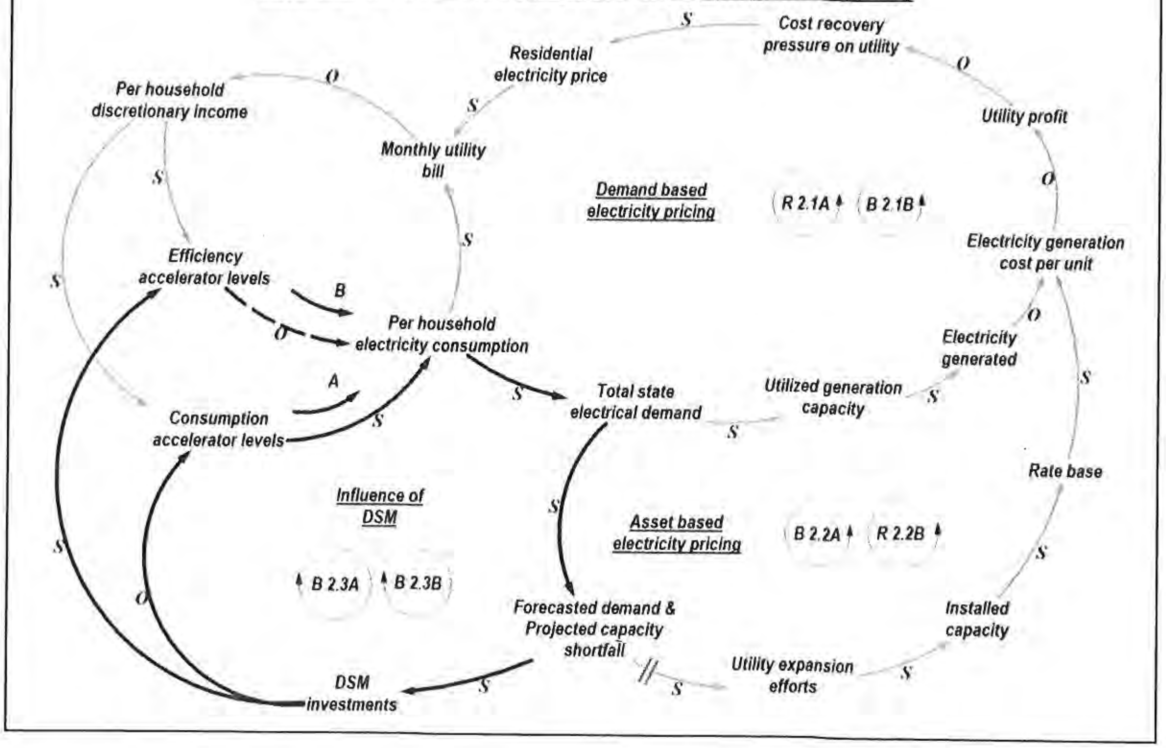
As discussed previously, the feedback due to consumption accelerators (loop B2.2A) is relatively more dominant and eventually the total state electricity demand is negatively associated with electricity pricing. In the case of a price hike due to capacity expansion, households are likely to take efforts to reduce power consumption by suppressing consumption accelerator levels; this will eventually balance the loop by lowering the state's total electricity demand hence reducing further needs to install new utility capacity. On the other hand, when there is no need to expand utility capacity, electricity prices may remain low but will boost R.El.C rates among households. This in turn can drive up total state demand and possibly cause the need to install new generation capacity, thereby explaining the balancing feedback of loop B2.2A.

According to reinforcing loop R2.2B, high electricity prices due to capacity expansions can suppress investments in efficiency upgrades due to lower discretionary income among households. Unnecessary electricity consumption due to household inefficiencies will cause total state electricity demand to rise and may bring the need for further utility capacity expansion in case of a projected shortfall. However, since high prices generally reduce overall demand by suppressing consumption accelerator levels, the reinforcing feedback corresponding to loop R2.2B is considered less significant.

2.2.3 INFLUENCE OF DEMAND SIDE MANAGEMENT

Investing in demand side management (DSM) strategies is the central aspect illustrated by balancing loops B2.3A & B2.3B (Figure 2.13). Demand side management refers to strategies employed by utility companies in order to manage electricity consumption on the consumer side of the power grid (Mohsenian-Rad, Wong, Jatskevich, Schober, & Leon-Garcia, 2010). A wide range of DSM strategies are employed by utilities and these can be categorized under two broad approaches - (i) strategic measures including conservation to manage the load curve[10], and (ii) consumer-side improvements in electricity use efficiency to minimize consumption.

Figure 2.13 : Influence of demand side management (DSM)



Utilities strengthen their DSM efforts by investing more when they forecast a high future demand and foresee a potential capacity shortfall. When they do suffer a shortfall, utilities might pursue DSM strategies in combination with capacity expansion. In loop B2.3A, DSM efforts are aimed at reducing impacts due to consumption accelerators, for e.g. through awareness programs or incentive programs to initiate voluntary conservation efforts to reduce careless consumption and appliance run times. In loop B2.3B, DSM efforts are aimed at improving efficiency levels among households in order to curb unnecessary electricity consumption. These efforts are expected to bring down both, per household R.El.C and the total state residential electricity

[10] Load curve in the utility sector refers to the electricity consumption by power consumers plotted with reference to time.

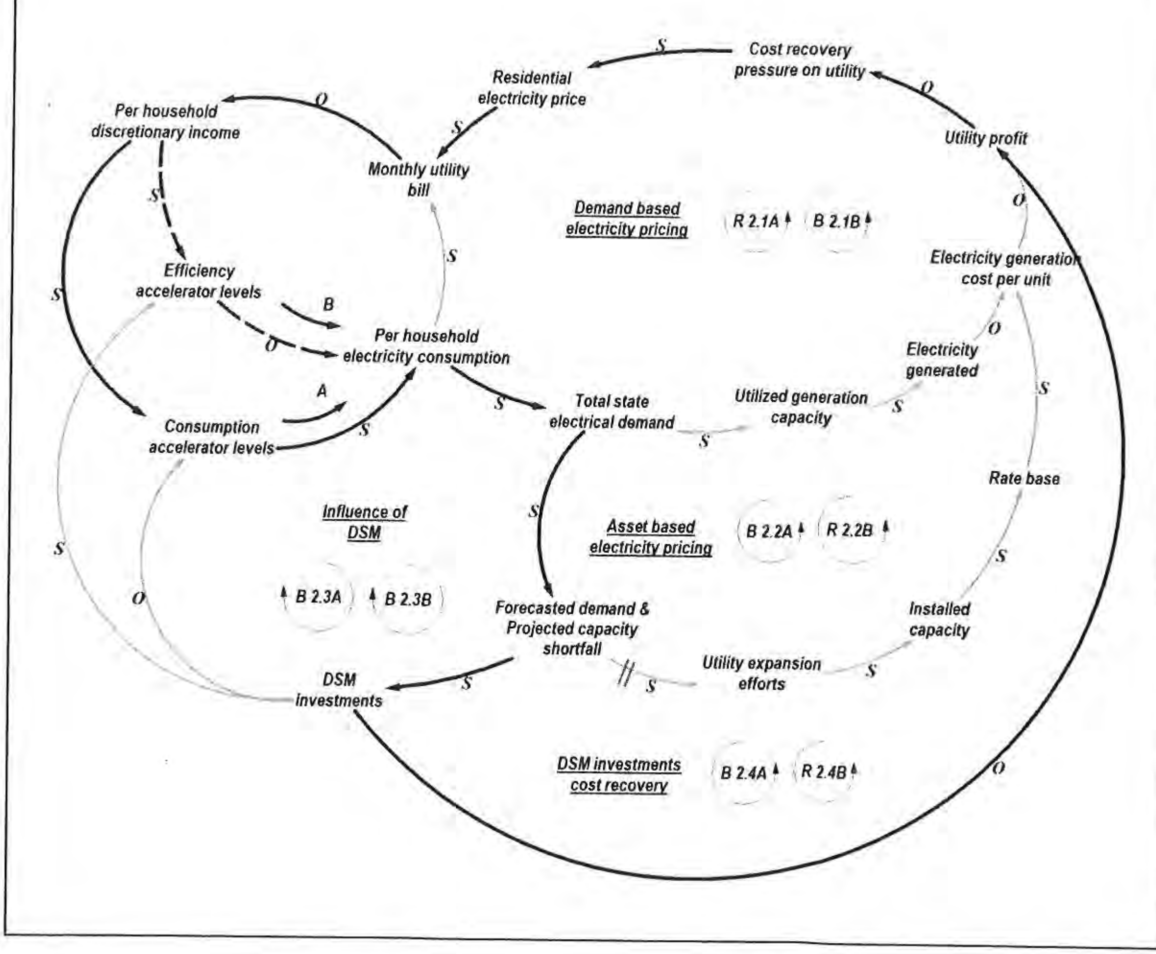
demand. The resulting feedback will help in balancing out the initially high forecasted demands or any projections in capacity shortfall. This explains the goal seeking behavior of balancing loops B2.3A&B.

On the other hand, when residential electricity demand in the state is low with less likeliness of a capacity shortfall, utilities may be reluctant to invest in DSM measures to avoid further undercutting the demand. Under such a scenario, utilities would be motivated to encourage more consumption by customers in order to better utilize their capacity and reduce per unit generation costs (loop R2.1A). Reduced DSM efforts will cause consumption accelerator levels to rise and leave household inefficiencies unchecked thereby resulting in higher household R.El.C and higher total state electricity demand. High demands can increase the likeliness of a future shortfall in capacity and would therefore have to be checked by strengthening DSM efforts.

2.2.4 DSM INVESTMENTS COST RECOVERY

DSM efforts can require significant financial investments by utilities and this may use up a fraction of their profits depending upon how big their investments are. Balancing loop B2.4A (Figure 2.14) illustrates the possibility of an electricity price hike in case utilities feel a pressure to recover large DSM investments; this will consequently impact total state residential demand as households will lower their consumption accelerator levels. Future forecasted demands could eventually drop hence necessitating investments cuts in DSM strategies. The dynamics of this loop are not usually felt as DSM investments are voluntary and made in the interest of reducing consumer demand and to lower the rate of utility expansion.

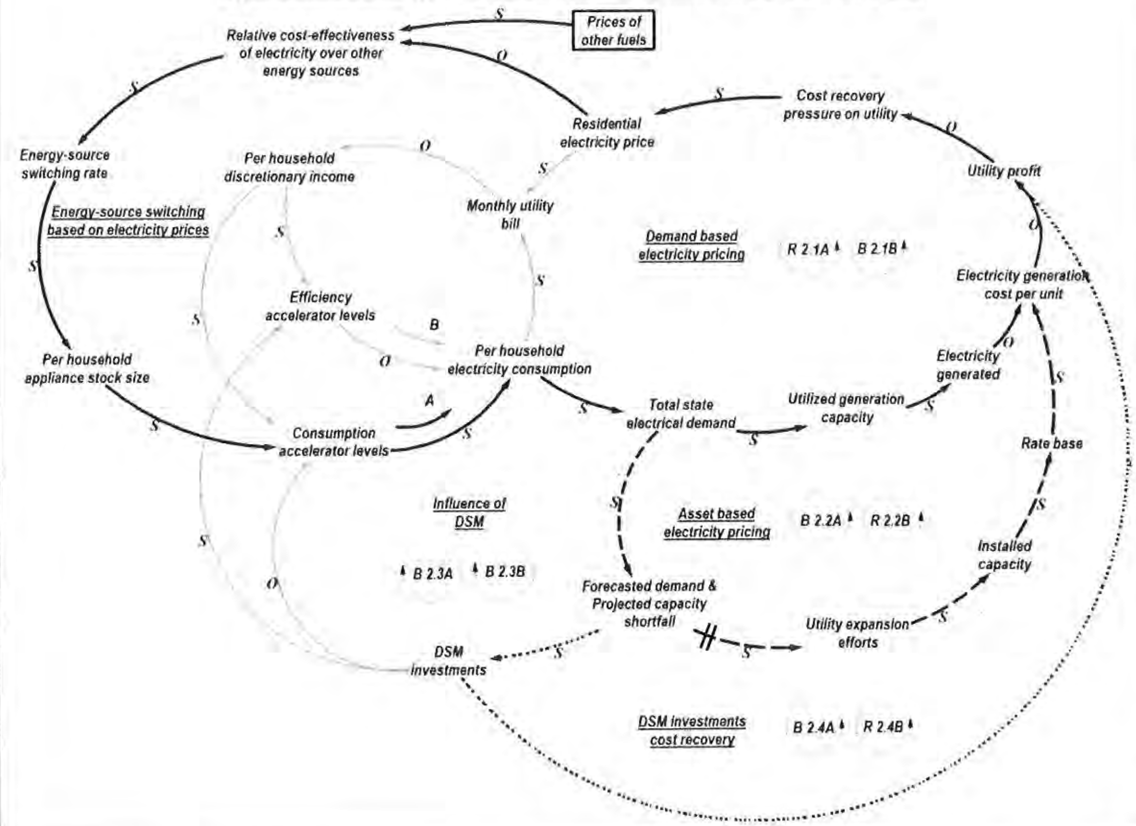
Figure 2.14 : DSM investments cost recovery



According to reinforcing feedback loop R2.4B, high electricity prices due to greater DSM efforts can make it difficult for households to invest in efficiency upgrades due to the impact on discretionary income. This can cause an increase in R.El.C rates across households and in the state total electricity demand. Higher demands may then call for stronger DSM efforts further increasing the electricity prices to customers. However as already discussed previously, the feedback due to efficiency accelerator levels (loop R2.4B) is relatively less significant compared to the feedback due to consumption accelerator levels (loop B2.4A).

2.2.5 ENERGY-SOURCE SWITCHING BASED ON ELECTRICITY PRICES

Figure 2.15 : Energy-source switching based on electricity prices



Residential electricity prices also influence household decisions regarding the type of appliances purchased, whether electrical or non-electrical. This is because electricity prices determine the operating costs of respective appliances. When prices are such that the operating costs of electrical appliances are cheaper than gas based counterparts, households may prefer using the former class of appliances to save money. Such decisions can increase the energy-source switching[11] rate across households by purchasing more electrical appliances. On the contrary, when cost-effectiveness of using electrical appliances is relatively lower, then households might prefer using gas or other fuel based appliances. Hence electricity prices can influence energy-source switching in turn affecting household's electrical appliance stock size which is a

[11] The term *energy-source switching* in this paper refers to the transition from traditional fuel use towards electricity use and not vice versa.

consumption accelerator. Feedback dynamics with respect to energy-source switching are similar to those represented by loops R2.1A, B2.2A & B2.4A; the only difference being that the variations in consumption accelerator levels is due to energy-source switching among households and not due to their discretionary income levels. Besides electricity prices, the prices of other fuels also determine the relative cost-effectiveness of electricity and is considered an exogenous variable that influences energy-source switching among households.

Note that the household and utility level dynamics explained so far focus only on 'per household' residential electricity consumption. Except for household size, all other variables among the household and utility level dynamics influence 'per capita' residential electricity consumption in similar fashion. Unlike per household R.El.C which is positively associated with household size, per capita R.El.C is negatively associated with the number of members in a household. A larger household size implies that the total electricity consumption is shared among more household members resulting in lower per capita consumption. Table 2.2 shows how per capita expenditure on basic requirements decreases as household size increases.

Table 2.2 : Per capita expenditures for different family (household) sizes and income ranges, Urban United States, 1960-61.

	Family Disposable Income							
	$1,000-1,999	$2,000-2,999	$3,000-3,999	$4,000-4,999	$5,000-5,999	$6,000-7,499	$7,500-9,999	$10,000-14,999
Mean Money Income After Taxes	$1,692	$2,572	$3,583	$4,668	$5,593	$6,783	$8,623	$11,811
Family Size	Food Expenditure Per Family Member							
Two	309	378	459	511	535	629	726	840
Three	208	263	340	383	422	470	569	659
Four	—*	251	283	315	351	407	465	549
Five	—*	203	256	279	294	353	410	462
Six or more**	—*	169	183	221	250	282	330	376
	Housing, Shelter, Utilities and Operation Per Member							
Two	351	454	578	673	707	880	1,049	1,219
Three	239	312	391	459	508	608	686	875
Four	—*	289	297	347	406	458	523	652
Five	—*	206	270	271	317	376	404	535
Six or more**	—*	134	155	196	223	269	319	349

Source: (Cutright, 1971)

In summary, the various factors and dynamics that have a role to play in influencing 'per household' and 'per capita' electricity consumption rates have been laid out in this chapter. The discussions thus far will form the basis for subsequent chapters to develop a dynamic hypothesis that would answer the primary research question i.e. what is causing per capita and per household residential electricity consumption rates in Virginia to grow rapidly?

3 ANALYSES OF 'HIGH RESIDENTIAL ELECTRICITY CONSUMPTION' SCENARIOS

The following chapter makes use of dynamics described in chapter 2 to identify possible scenarios that can potentially lead to high per capita and per household residential electricity consumption rates. Outlining such high residential electricity consumption scenarios[12] will provide the basis to formulate a dynamic hypothesis that explains why Virginia's growing per capita and per household residential electricity consumption rates are climbing annually. Consistent with the analyses in chapter 2, the discussion in this chapter utilizes two different lenses for understanding this problem: household-level analysis, and utility-level analysis.

3.1 HOUSEHOLD LEVEL ANALYSIS

According to the simplified household level CLD shown in Figure 2.10, high residential electricity consumption rates[13] occur as a direct result of either a **surge in electricity consumption accelerator levels** or a **decline in efficiency accelerator levels**. The possible reasons behind the occurrence of these two conditions among high R.El.C scenarios are explained as follows.

3.1.1 CAUSES OF SURGE IN CONSUMPTION ACCELERATORS

1. **Excessive discretionary income** has a reinforcing effect on the levels of consumption accelerators which in turn yields high per capita and per household electricity consumption rates. The following are system conditions that prevail amidst high R.El.C scenarios due to the influence of discretionary income:

[12] The term 'High residential electricity consumption (R.El.C) scenario' used throughout this chapter refers to a scenario where 'per capita R.El.C' and 'per household R.El.C' rates are both high.

[13] The term 'residential electricity consumption (R.El.C) rates' used throughout this chapter refers to both 'per capita R.El.C' and 'per household R.El.C'.

- Households living in larger homes which in turn increase the need for electrical home services.
- Larger appliance stock per household.
- Careless electricity consumption attitude and reduced voluntary conservation efforts that are associated with an affluent lifestyle.

2. Besides discretionary income, various exogenous factors also have reinforcing effects on consumption accelerators. These include:
   - **Higher heating or cooling degree day figures,** which increase space cooling or heating demands of households respectively.
   - **High sale or rental prices of homes,** since this can make it difficult for households living in ageing, inefficient homes to upgrade to newer and more efficient homes.
   - **High market prices of building refurbishment materials,** as this would slow down their diffusion since households may not often be willing to make such costly investments towards efficiency upgrades.
   - **Cheaper market prices of electrical appliances,** as they boost market diffusion rates and increase appliance stock sizes across households.
   - **Increased energy-source switching rates,** which may be triggered by greater relative advantages of electrical over non-electrical appliances resulting from technological advancements. This can also add to the appliance stock of households.
   - Household size (i.e. number of people per household), since **larger households** exert pressure on consumption accelerators such as electrical home services and appliance stock due to the presence of more individuals in the household; this consequently induces a high R.El.C scenario. While **smaller households** may be economically beneficial, they are also likely to increase the per capita R.El.C since major consumption demands like heating and cooling will now be shared among lesser number of people. In addition, the discretionary spending capacity of smaller households tends to be higher since their basic

expenditures are relatively lower due to less number of household members. This in turn can reinforce consumption accelerators thereby resulting in high R.El.C rates.

3. Loop polarities play a significant role in determining how long a scenario's outcome will prevail. As per Figure 2.10, consumption accelerators are associated with balancing loop in which there is a **delay involved before the loop's corrective action can take effect and R.El.C rates can actually start declining**. This is due to the possibility that a household's spending capacity may remain unaffected until its discretionary income drops below a certain threshold beyond which significant economic pressures are felt; this is usually the case in high income families. During such a delay, R.El.C rates will either remain steady or continue to rise but will rarely decline. There is even further delay involved as households will need time to change their consumption habits in order to noticeably reduce their electricity consumption.
4. Effect of efficiency accelerator loop (R) on the consumption accelerator loop (B): Due to the reinforcing behavior of the efficiency loop, savings that result from a significant improvement in efficiency conditions will reinforce a household's discretionary income; this will allow for even further efficiency investments and cost savings (Figure 2.10). However, efficiency improvement as a household-level policy measure to decrease electricity consumption can have an unintended consequence. Higher efficiency levels from appliance or home upgrades will result in cost savings that add to the household's discretionary income; this in turn is likely to cause a surge in consumption accelerators as discussed earlier in section 'a'. The surge is mostly due to careless consumption attitudes since the operating costs of appliances are relatively lower after efficiency improvements. This chain of events is called **the rebound effect** (Berkhout, Muskens, & W. Velthuijsen, 2000) and contributes towards a high R.El.C scenario.

3.1.2 CAUSES OF DECLINE IN EFFICIENCY ACCELERATORS

1. **Low discretionary income** contributes towards high R.El.C scenarios too; this is because efficiency accelerator levels are undermined due to reduced capacity to invest in energy efficient appliances and home improvements. The following conditions are likely to prevail in such scenarios:
   - **Slower appliance turnover rate,** which results in ageing appliances which grow in inefficiency levels with time.
   - **Purchase of low-end appliances**, especially those which are not efficiency certified. Such appliances are electrically more intensive compared to their efficiency certified but more expensive counterparts.
   - **Inability to invest in new homes or home refurbishments** in order to minimize the inefficiencies associated with ageing homes.
2. Exogenous factors that have an undermining effect on efficiency accelerators:
   - **Old homes,** as they are generally less energy efficient, depending on how well they are refurbished.
   - **Larger households,** since they are likely to be left with less discretionary income to invest in efficiency improvements, either home refurbishments or more efficient appliances. The reason is because their basic expenditures are relatively higher due to more number of household members.
   - **High market prices of more efficient appliances,** since consumers will settle for lower priced appliances which tend to be relatively less efficient.
   - **High market prices of building refurbishment materials,** since this would slow down their diffusion rates and households may feel reluctant to invest in such expensive upgrades.

3. As per Figure 2.10, efficiency accelerators are associated with reinforcing loop (R). High household electricity consumption resulting from low initial efficiency levels will choke the household's discretionary income therefore restricting further efficiency investments. This endless reinforcing dynamic will ultimately give rise to a scenario with high per capita and per household R.El.C rates.
4. Effect of consumption accelerator loop (B) on the efficiency loop (R):

   High R.El.C rates in the case of a surge in consumption accelerators will cause a decline in the household's discretionary income due to increased utility bills. For example, larger housing units imply higher utility bills in addition to higher mortgage payments and maintenance costs. This will consequently choke the household's spending capacity making it almost impossible to invest in efficiency upgrades until the consumption accelerator loop (B) balances itself (Figure 2.10). This sequence of events will eventually induce a high R.El.C scenario.

Highlighted so far are the household level system conditions which give rise to high residential electricity consumption rates. The following section will explore further causes of high R.El.C rates due to dynamics at the utility level.

3.2 Utility Level Analysis

According to the utility level CLD shown in Figure 2.15, high residential electricity consumption rates occur as a result of ***affordable retail electricity prices*** or ***insufficient demand side management (DSM) efforts***. Low retail prices can lead to a surge in consumption accelerators since lower utility bills would leave households with more discretionary income. Reduced economic pressures will eventually allow for excessive consumption of electricity amongst residences. Low electricity prices furthermore incentivize home owners to use more electricity-based appliances due to the energy source being cost effective, therefore increasing energy-source switching rates among households. However, in a 'low price elasticity of demand' scenario, household R.El.C rates may continue to rise despite high electricity prices. This is because when a household is more affluent, higher utility bills may not have a significant impact on its discretionary income and R.El.C rates are likely to rise as long as economic pressures are not felt by the household. Besides electricity prices, insufficient DSM measures on the part of utilities also induce high household R.El.C rates as inefficiencies among residences are left unattended.

3.2.1 REASONS BEHIND LOW RETAIL ELECTRICITY PRICING

The following conditions among utility level endogenous variables account for low retail prices:

1. A **high total demand for residential electricity in the state** allows for more efficient utilization of utility generation capacity, and hence lower electricity generation costs and retail prices.

2. **Slower capacity expansion rates** by utilities helps them avoid immediate pressures to recover capital investment costs, hence allowing them to maintain low retail electricity prices (Ford, 1997).

3. **Lesser investments in demand side management** also helps utilities maintain low electricity prices by avoiding additional cost recovery pressures.

Note that a high R.El.C scenario due to low electricity prices will persist until total electricity demand increases to a threshold beyond which a capacity expansion or a rapid push for DSM to curb demand is necessary. These corrective actions can cause a potential electricity price hike as they increase utility operating costs. There also exists a period of delay before electricity prices can actually climb since it takes considerable period of time for a capacity shortfall to occur and also for new capacity installations to come online.

3.2.2 Reasons behind insufficient DSM efforts

Minimal efforts to promote demand-side management (DSM) can be the status quo with a utility whose electricity generation capacity is underutilized. In such a case, the utility is likely to place lower priority on DSM measures since such efforts will only further reduce electricity consumption rates, undercut the total demand and lead to even lower utilization of generation capacity. This would only go on to accelerate the utility death spiral (as described by Loop R2.1A in Figure 2.11) and hence utilities have a strong incentive to compromise on demand side management efforts. Low monetary investments by utilities and less Government and third party provisions are other reasons behind insufficiencies in demand side management efforts.

Insufficiency in DSM efforts will drive up consumption accelerators and suppress efficiency accelerators. The resulting increase in household electricity consumption will accelerate the reinforcing behavior of the demand based pricing loop (effect of loops B2.3A&B on R2.1A). Hence household consumption will continue to increase endlessly therefore giving rise to a high R.El.C scenario.

3.2.3 General dynamic hypothesis

Up to this point, it has been established that residential electricity consumption trends in the U.S are driven by a combination of factors which, under the right circumstances, can together create a "perfect storm" on account of which growth in per capita and per household residential electricity consumption rates are virtually inevitable. This perfect storm emerges out of cohesive interaction between a collection of reinforcing and balancing feedback dynamics described thus far. In short, this perfect storm can be described as a situation in which

1. discretionary incomes of households incomes are on the rise
2. household consumption accelerator levels are rising and household inefficiencies are left unchecked

3. utilities, in order to maintain a profitable 'business as usual' strategy and to minimize under-utilization of their generation capacity, remain motivated to increase consumer demand by maintaining affordable prices and neglecting investments in demand-side management strategies
4. electricity costs are low enough to encourage more consumption among households and promote energy-source switching
5. the price elasticity of electricity demand is low which means that increases in retail prices of electricity have little effect on demand

The feedback dynamics under the existence of such conditions work relentlessly to drive up consumption with time. A sufficiently large capacity shortfall occurs eventually that justifies expensive capacity expansion by utilities. Although utilities may have to recover huge costs in order to pay for the expansion, such costs are shared by increasingly more consumers and the electricity prices are seldom enough to significantly dampen the growth in demand. Moreover, after expansion, utilities have strong disincentives to promote DSM efforts, but rather have strong incentives to promote demand growth until the newly expanded generation capacity is fully utilized. The net result of the above dynamics is hence a perfect storm in which a growth in rapid R.El.C rates is imminent. Chapters 4 and 5 are focused on evaluating the validity of the above described dynamic hypothesis with respect to Virginia.

4 VIRGINIA'S TRENDS AND RELEVANT INFERENCES

We now turn our attention to the original problem that this dissertation addresses: ***Why does Virginia exhibit trends in per capita and per household electricity consumption from 1980 and 2010 that are so different than in the benchmark states of California and New York?*** In order to answer this question, the following chapter first analyzes and evaluates the validity of the dynamics described in chapters 2 and 3 with respect to Virginia. Historical trends of major relevant determinants are analyzed for Virginia to determine how evident the corresponding dynamics induced by them are in the State. Chapter 5 then compares these trends with those of the benchmark states to identify which of those dynamics are uniquely causing per capita and per household R.El.C rates to climb rapidly in Virginia. Note that weather conditions have already been considered not to be a major driving force behind Virginia's R.El.C trends and are hence not discussed in the following chapters.

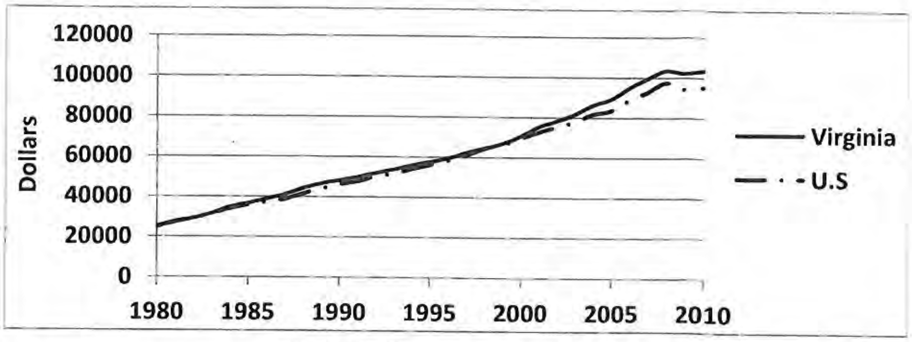
4.1 HOUSEHOLD LEVEL DETERMINANTS

4.1.1 DISCRETIONARY INCOME

The study uses annual data on *average disposable income per household* to infer a trend for the *average discretionary income per household*[14] since specific historical data could not be obtained. Figure 4.1 illustrates the historical trend in *average disposable income per household* for Virginia alongside that of the United States. Between 1980 and 2010, the average disposable income per household amongst Virginia's residences has seen over a four-fold increase from $25162 to $103401 at 4.7% avg. annual growth rate. This trend is very close to the U.S. average.

[14] Discretionary income per household represents the average income left to a household after taxes and other mandatory expenses are deducted.

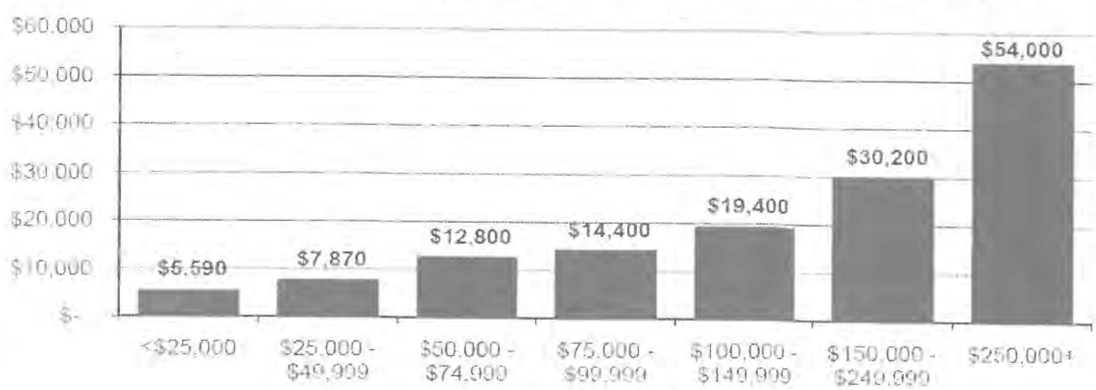
Figure 4.1: Average disposable income per household, 1980-2010.



Source: (CensusBureau, 2011)

Figure 4.3, according to a 2011 report (Simmons, 2011), illustrates the correlation between a household's discretionary spending and its real disposable income. Based on Virginia's disposable income figures, the chart implies that discretionary spending among the state's households has approximately increased from roughly $7,870 to $19,400 during the thirty year window, suggesting a corresponding increase in *household discretionary income* figures.

Figure 4.2: 'Average annual household discretionary spending' vs 'household disposable income'.



Source: (Simmons, 2011)

The rise in Virginia's discretionary income levels across between 1980 and 2010 signifies the following implication:

1. Greater discretionary income levels imply the possible reinforcement of the various consumption accelerators. These are square footage of residences, appliance stock per household and careless consumption attitudes.

2. Higher discretionary income enables households to absorb increased utility bills before feeling a strain on their budget. The increases in utility bills maybe either due to greater R.EL.C rates or increases in electricity prices.
3. Although Virginia's households have seen increases in discretionary income, it is likely that they are not making the choice to invest in efficiency upgrades since R.El.C rates are continuing to climb. Virginians might not be as willing to replace ageing inefficient appliances with new products on the market, or make the extra investment required to purchase relatively expensive but more efficient appliances or even invest in new homes or refurbishment efforts to improve efficiency. The negligence to make such valuable choices is chiefly attributed to high initial investment costs and long payback times.

4.1.2 APPLIANCE RELATED TRENDS

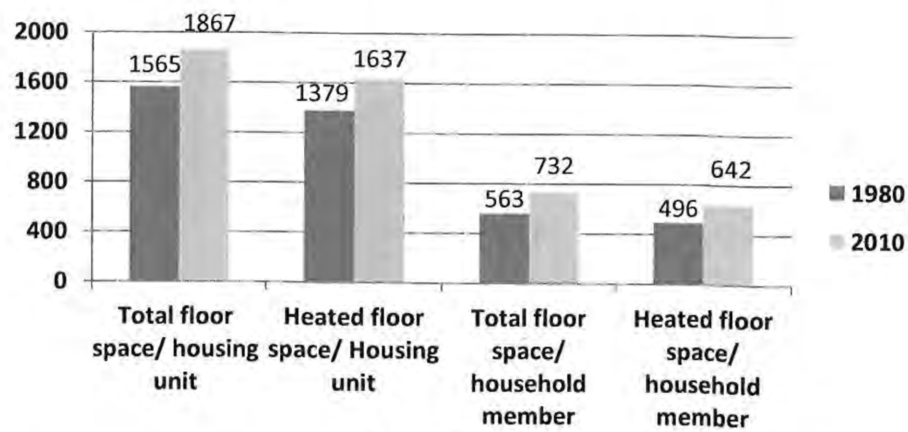
A dramatic increase in the penetration of consumer electrical appliances and electronics has been observed across the United States since the 1980s (Fernandez, 1999); this can generally be attributed to them becoming more cheaper and affordable with time (Yost, 2010). Appliances such as refrigerators, television sets and washing machines have reached high levels of saturation. This trend in market diffusion of appliances can be assumed to be the same with Virginia and hence the stock of appliances across the state's households is expected to have increased over the years.

Evidence from market data and interviews confirm that the purchase prices of more efficient electrical appliances are relatively higher than their less efficient counterparts. This forms a general barrier that slows down the penetration of more efficient appliances into consumer households (Attali, Bush, & Michel). Since this is a general fact across the country, it is speculated that the accelerating R.El.C trends in Virginia could be partly due to households purchasing low end home appliances and electronics that are not efficiency certified.

4.1.3 Residential Square Footage

RECS data suggests that households among the Southern states are now living in larger homes with respect to floor space compared to 1980 (Figure 4.3). The trend is assumed to be the same for Virginia which is one among the Southern States. Increased residential square footage of housing units implies greater electricity demands for home services like electrical heating, cooling, lighting, etc.

Figure 4.3: Residential square footage in Virginia.



Source: (EIA, 2010)

4.1.4 Age of Housing Units

According to U.S Census data, the number of housing units in Virginia aged 30 years or less has dropped 8% between 2000 and 2010, while the number of housing units aged 30+ has increased by 50%. This implies that the number of existing structures ageing out into the 30+ category is more than the number of new structures built during the ten year period. In other words, Virginia has a large stock of ageing housing units.

Table 4.1: Number of housing units by age in Virginia.

Year	Total	30 years and less		30 years +	
		Count	% of total	Count	% of total
2000	2904192	1719964	59.2%	1184228	40.8%
2010	3315739	1566881	47.3%	1748858	52.7%

Source: (CensusBureau, 2012a)

Table 4.1 highlights the fact that the percentage of homes in Virginia older than 30 years formed the majority in 2010. This growth in the number of older homes is an indicator that efficiency accelerators have possibly declined in Virginia.

4.1.5 HOUSEHOLD SIZE (# HOUSEHOLD MEMBERS)

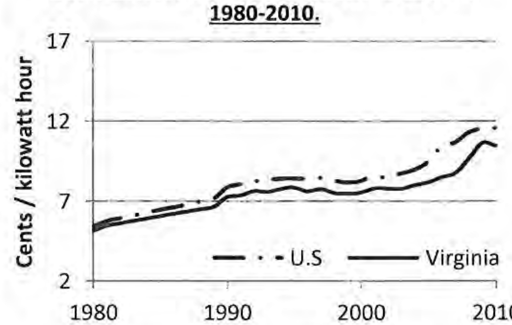
The average household size in Virginia has dropped from 2.63 people in 1980 to 2.57 people in 2010 (CensusBureau, 2012b). This may appear to be a very small change but a decreasing trend in household size implies that household electricity consumption for various services will be shared among lesser household members. Per capita residential electricity consumption is therefore bound to increase.

4.2 UTILITY LEVEL DETERMINANTS

4.2.1 RETAIL ELECTRICITY PRICES

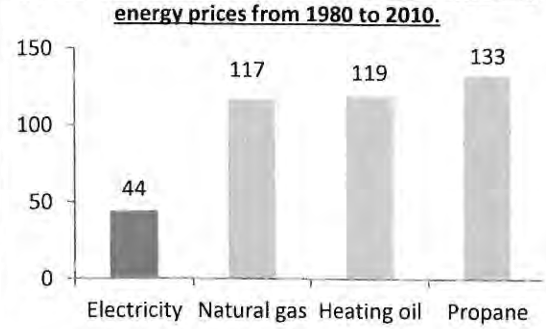
Historical data in Figure 4.4 shows that retail electricity prices in Virginia have consistently remained below the National average price between 1980 and 2010 (EIA, 2012a). This indicates that Virginians have enjoyed relatively lower retail prices compared to several other states. Furthermore, electricity prices have grown only by 44% unlike the prices of natural gas, heating oil and propane which have exhibited growths of over 100% across the thirty years. This has allowed Virginians to rely on electricity as a cost-effective energy source.

Figure 4.4: Retail electricity prices by state, 1980-2010.



Source: (EIA, 2012a)

Figure 4.5: Virginia percentage change in residential energy prices from 1980 to 2010.



Source: (EIA, 2012b)

The above electricity pricing trends suggest the following:

1. The growth in Virginia's retail electricity prices between 1980 and 2010 has not had a significant impact on the discretionary incomes of households and hence has allowed them to consume more electricity with hardly any economic pressures. This low price elasticity of demand can be attributed to the significant growth in the discretionary income of households during the same time frame.
2. Electricity has remained reliably cost-effective in the state compared to other energy sources. This partly explains why a large percentage of Virginia's residential energy use comes from electricity.

4.2.2 UTILITY INVESTMENTS IN DEMAND SIDE MANAGEMENT (DSM)

History of DSM efforts in Virginia show insignificant investments by utilities that are almost negligible. The above fact is supported by the following data from the *American Council for Energy-Efficient Economy* (ACEEE) State Energy Efficiency Scorecards, corresponding to the time frame between 2006 and 2011 (Eldridge et al., 2008; Eldridge, Prindle, York, & Nadel, 2007; Molina et al., 2010; Sciotino, 2011):

1. The ACEEE State Energy Efficiency Scorecards show that Virginia has consistently scored 0 out of 15 points in three categories: Utility spending on electricity efficiency programs, net electric savings and utility incentive programs for efficiency improvements.
2. Table 4.2: Net utility spending in electric efficiency programs

year	VA	U.S
2006	$84,000	$1.6 Billion
2007	$1,000	$2.2 Billion
2009	$400,000	$3.4 Billion
2010	$200,000	$4.6 Billion

During these years, the annual DSM investments by VA utilities as a percentage of their annual revenues have been negligible (less than 0.05%).

3. Table 4.3: Net annual electric savings by utilities

year	VA	U.S
2006	63 MWh	7.8 million MWh
2007	83 MWh	9.8 million MWh
2008	14 MWh	10.6 million MWh
2009	1029 MWh	13.1 million MWh

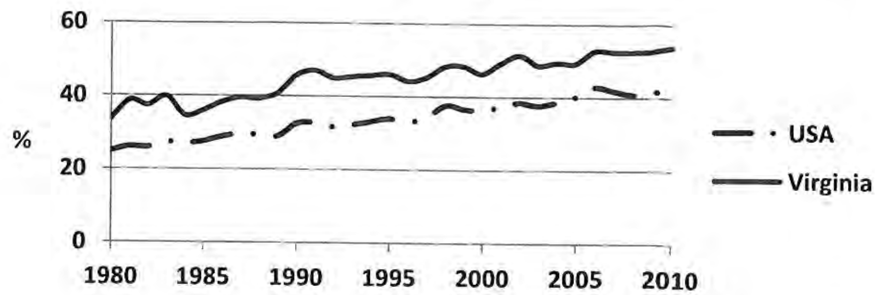
The effectiveness of DSM efforts is positively associated with the resulting electricity savings. Virginia's annual electric savings as a percentage of its annual net electrical sales have also been negligible (less than 0.05%).

It is evident from the above facts that Virginia's demand-side management efforts have been insufficient in managing the state's rising electricity demands through efficiency and conservation. This in turn has allowed consumption accelerators to gain momentum and inefficiencies to persist among Virginia's residences hence inducing a high R.El.C scenario in the state.

4.2.3 PERCENTAGE OF RESIDENTIAL ENERGY USE FROM ELECTRICITY:

As already mentioned in chapter 1, the percentage of Virginia's residential energy use from electricity has been much higher than the National average over the past three decades. The energy use from electricity fraction amongst Virginia's residences has increased from 34% in 1980 to 54% in 2010 (Figure 4.6). This is a definite factor behind the growth rates in Virginia's per capita and per household R.El.C rates.

Figure 4.6: Percentage of residential energy use per household from electricity, 1980-2010.



Source: (EIA, 2012b)

Following are some reasons behind the above trend:

1. As discussed earlier, electricity in Virginia has consistently remained a cost-effective energy source. Affordable prices have always encouraged households to consume more electricity in relation to other fuels and possibly even causing households to switch from non-electrical energy sources.
2. According to RECS Survey data, majority of Virginia's households in 2009 used electricity as the energy source for major applications like space heating, water heating and cooking. Only a minority of households used alternate fuels like natural gas, propane and LPG for these applications.

Table 4.4 Fuels used for various end uses among VA homes, 2009.

Service type	Number of VA homes (in millions) using		
	Electricity	Natural Gas	Propane
Space heating	2.2	1.1	0.3
Primary	1.6	1.0	-
Secondary	0.8	0.3	0.3
Water heating	1.8	1.1	-
Cooking	2.2	0.8	0.1
Other	3.0	0.2	1.3

Source: (EIA, 2010)

This has been the case despite wide spread agreement that gas-based appliances are relatively more fuel efficient and environmentally friendly (AGA, 2012). It may therefore be implied that Virginians have preferred electrical appliances for their cost effectiveness and their operating convenience.

3. Besides heating and cooking appliances, many other new consumer products today use electricity (mobile devices, computers, personal gadgets, etc.). The fact these products have gotten cheaper with time combined with more affluent households and affordable electricity prices in Virginia is another possible reason for the state's high percentage of energy use from electricity.

Note that although there is the possibility of energy-source switching having occurred in the state, it is however difficult to determine how much it has contributed to the growth in R.El.C rates with the limited data available.

4.3 SUMMARY OF FACTS: SOURCES OF GROWTH BEHIND VIRGINIA'S R.EL.C RATES

Data suggest that 'per household' and 'per capita' residential electricity consumption in Virginia's residential sector have grown due to a combination of several trends that together feed dynamics to induce a continuous growth in the state's R.El.C rates. The various trends discussed so far in the chapter are briefly summarized below.

Virginia's households have become more affluent in recent years and are able to absorb greater utility bills due to their increased spending capacities. Greater affluence has allowed them to invest more in electrically intensive lifestyle improvements. Electrical appliance stock sizes have increased across households due to their preference over electrical space heating, water heating, cooking, etc. and also due to increasing use of personal electronics. Households are also now living in larger residences which further increase the need for electrical home services like heating, cooling, lighting, etc. The size of households (# members) in Virginia has gradually reduced over the years meaning that electrical services especially space heating and cooling are now shared among fewer members thus increasing per capita residential electricity consumption.

The above trends combined with affordable electricity prices have further accelerated per capita and per household R.El.C rates in Virginia. Electricity has also remained more cost-effective compared to other energy sources in the state and is hence expected to have caused households to switch energy sources towards using electricity. Greater relative cost-effectiveness of electricity, preference over electrical appliances by majority of Virginia's households and the increase in use of personal electronic gadgets have all resulted in electricity accounting for the greater percentage of energy use in the state and eventually causing the growth in R.El.C rates. Besides the trends in electricity prices, the increase in discretionary incomes among Virginia's households have also lowered the price elasticity of electricity demand.

The data further suggests low overall efficiency levels among Virginia's households. Primarily, demand side management efforts in the state have been negligible implying that inefficiencies among households have been left unchecked and conservation measures have been insufficient. Secondly, Virginia has a large stock of ageing housing units meaning that inefficiencies prevailing in such units could be causing its occupants to consume electricity unnecessarily. Furthermore, the growth in residential electricity consumption rates with simultaneous growth in the affluence of Virginia's population suggest the possibility that households are reluctant to invest in efficiency upgrades to suppress those consumption rates. The penetration of efficiency upgrades into consumer residences is further slowed down due to their higher prices in the market. Since the analysis typifies low overall efficiency levels among the state's households, it is mostly skeptical if the rebound effect may have contributed significantly to the growth in Virginia's R.El.C rates.

The above summary may be interpreted as the dynamic hypothesis that answers why Virginia's per capita and per household residential electricity consumption rates have been growing rapidly between 1980 and 2010. However, at this point in the analysis, it is not clear if the various conditions summarized uniquely prevail in Virginia or are common across the benchmark states too. In order to determine this, chapter 5 involves a comparative analysis in which Virginia's trends among the relevant R.El.C determinants are compared with those of the benchmark states, namely California and New York.

5 COMPARATIVE ANALYSIS WITH BENCHMARK STATES

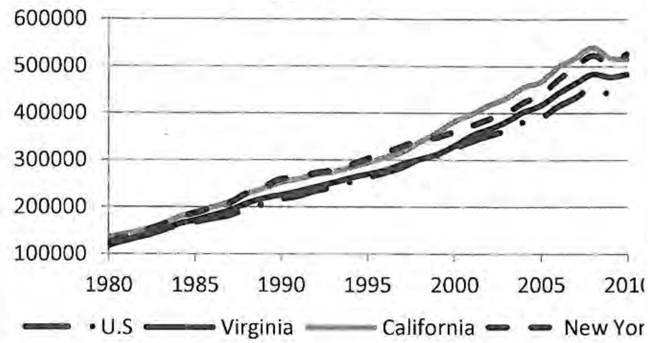
The comparative analysis in this chapter aims to identify the discrepancies that exist between Virginia and benchmark states and hence identify which of the hypothetical conditions summarized in chapter 4 uniquely drive 'per capita' and 'per household' residential electricity consumption growth in Virginia. In other words, the analysis helps to further enhance the dynamic hypothesis specifically for Virginia. The study also provides Virginia's policymakers with insight on opportunities for policy action and forms the basis to develop meaningful recommendations towards addressing the issue. Findings from the analysis suggest that residential square footage, household size, age of housing units, retail electricity prices, DSM investments and the percentage of residential energy use from electricity are the major factors that have uniquely influenced Virginia's residential electricity consumption rates in comparison with the benchmark states.

5.1 COMPARISONS WITH RESPECT TO HOUSEHOLD LEVEL DETERMINANTS

5.1.1 DISCRETIONARY INCOME

Near similar trends in annual household discretionary spending according to Figure 5.1 and Table 5.1 imply that corresponding discretionary incomes, respective annual growth rates and percentage changes for Virginia and the benchmark states are fairly comparable during the thirty year period. This indicates that although the rising trend in annual discretionary income may have contributed to Virginia's rising R.El.C trends, the trend is not unique to Virginia and is common across the benchmark states.

Figure 5.1: Annual discretionary spending per household, 1980-2010.



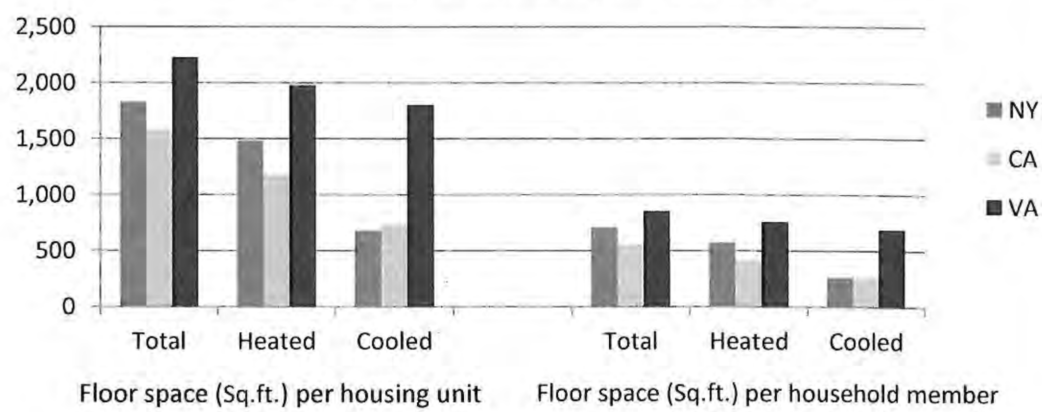
Source: (CensusBureau, 2011)

Table 5.1: Growth in annual discretionary income between 1980 and 2010.

Annual discretionary spending per household		
State	% change	Annual growth rate
US	233.5	4.5
VA	256.5	4.7
CA	239.9	4.7
NY	276.4	4.7

5.1.2 RESIDENTIAL SQUARE FOOTAGE

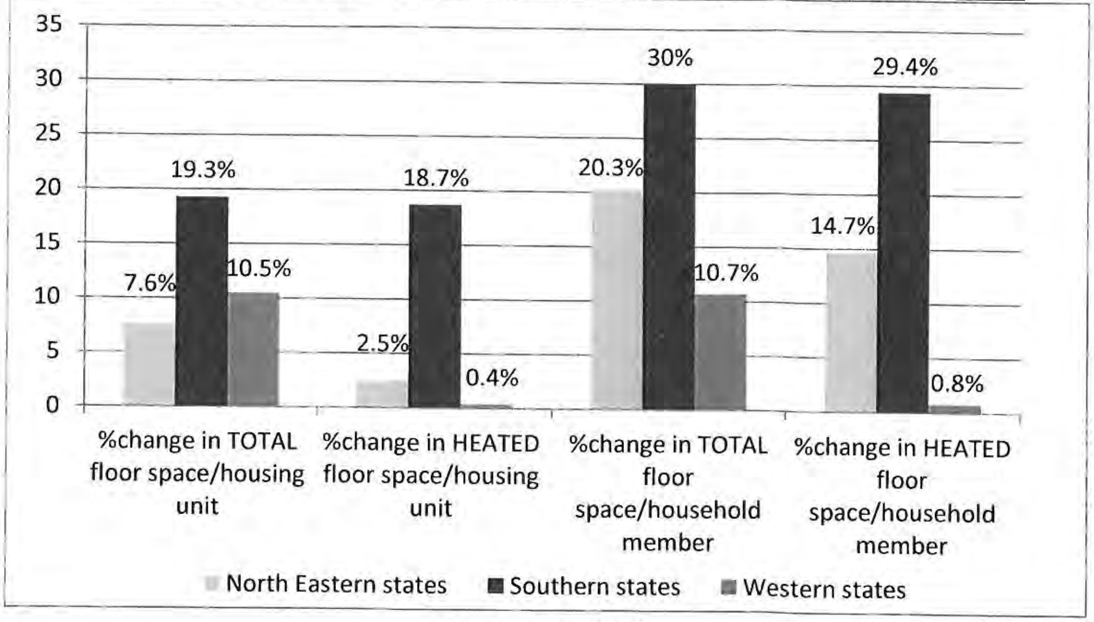
Figure 5.2: Average residential square footage, 2009.



Source: (EIA, 2010)

In 2009, according to Figure 5.2, the square footage per housing unit as well as per household member was noticeably higher in Virginia than in the benchmark states. This indicates that Virginia's households are now living in larger residences than those in California and New York; also each Virginian household member is now occupying more floor space to himself compared to those in the benchmark states.

Figure 5.3: Percentage changes in residential square footage between 1980 and 2009.



Source: (EIA, 2010)

A comparison of region specific data[15] corresponding to 1980 and 2009 finds that housing units among southern states have shown the highest percentage growth in residential square footage during the period, both total as well as heated floor space (Figure 5.3). Notice that the change in per capita floor space is more appreciable than the change in per housing unit floor space. Being a southern state, it is inferred that Virginia's annual growth rates in residential square footage, both total and heated, have been far higher than those of California or New York. The above differences between Virginia and the benchmark states have occurred despite the fact that discretionary income has grown quite evenly among all states. It is hence concluded that the growing trend in size of Virginia's housing units is unique to the state and is expected to be a major contributor to the state's rising R.El.C trends.

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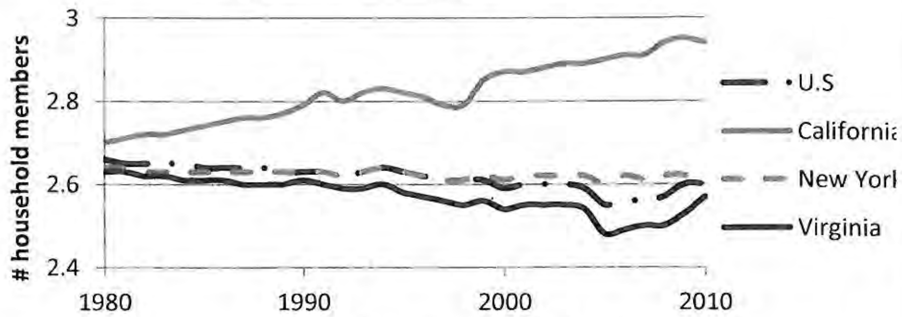
[15] New York, Virginia and California belong to the North Eastern, Southern and Western states respectively. The trend in residential square footage growth for each state is assumed to be the same as the respective regions they belong to.

5.1.3 HOUSEHOLD SIZE (# RESIDENTS PER HOUSEHOLD)

Figure 5.4: Household size, 1980-2010.



Census: (CensusBureau, 2012b)

The comparison in Figure 5.4 shows that Virginia has had the lowest average household size compared to the benchmark states between 1980 and 2010. The state's figures have also declined gradually and remained consistently below the national average during this time frame. The fact that the Virginia's household size has decreased over the years while the square footage of homes has increased translates into higher per capita electrical needs for services like heating, cooling and lighting among the state's households.

5.1.4 AGE OF HOUSING UNITS

Table 5.2: Number of housing units based on age category, 2000-2010.

Year	State	Total	30 years and less		Above 30 years	
			Count	Percentage of total	Count	Percentage of total
2000	CA	12214549	6179911	50.6	6034638	49.4
	NY	7679307	1985706	25.9	5693601	74.1
	VA	2904192	1719964	59.2	1184228	40.8
2010	CA	13552624	4971595	36.7	8581029	63.3
	NY	8050835	1506171	18.7	6544664	81.3
	VA	3315739	1566881	47.3	1748858	52.7

Source: (CensusBureau, 2012a)

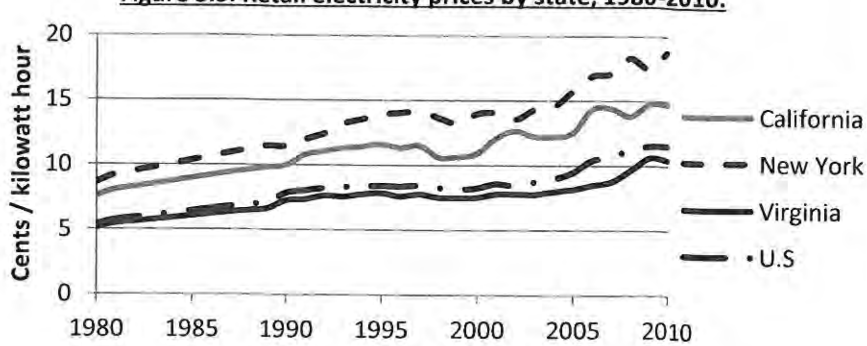
According to figures shown in Table 5.2, housing units aged above thirty years have increased and the relatively younger housing units have declined among all three states between 2000 and

2010. In fact, the older group of households formed the majority in 2010 among the three states. A closer look at the data shows that the percentage of homes older than thirty years has been the highest for New York between 1980 and 2010, followed by California. This could intuitively imply larger inefficiency levels associated with ageing homes and therefore higher per capita and per household R.El.C rates among those states. However, this has not been the case and R.El.C rates among California and New York have been significantly lower compared to Virginia despite the latter having a relatively smaller population of homes older than thirty years. This is a precursor towards the possibility of high efficiency levels prevailing amongst New York and Nevada's households which is also supported by the trends in demand side management among those states. However, the bottom line is that the increasing trend in the number of housing units aged above thirty years is common across all three states and not unique to just Virginia.

5.2 Comparisons with respect to utility-level determinants

5.2.1 Retail electricity prices

Figure 5.5: Retail electricity prices by state, 1980-2010.



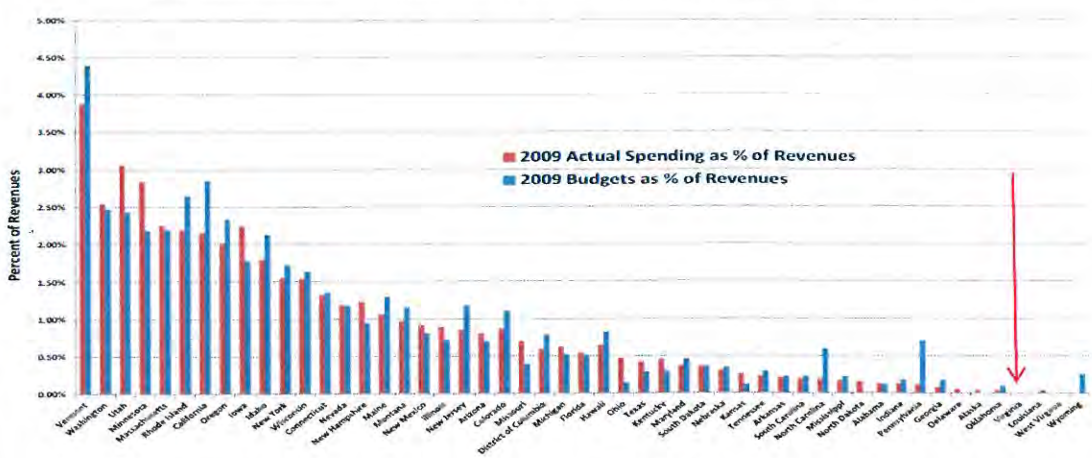
Source: (EIA, 2012a)

Figure 5.5 shows that Virginia's retail electricity prices have been much lower than California, New York and even the National average between 1980 and 2010. Virginia has had the cheapest prices compared to the benchmark states since 1980. It is apparent that the high consumption rates amongst Virginia's households can be largely attributed to the fact that the state has been enjoying relatively more affordable prices compared to other states over a long period of time.

5.2.2 Utility Investments in Demand Side Management (DSM)

One of the major findings of this study is that Virginia's investments in DSM are negligible and not worth mentioning compared to almost all other states in the United States. Figure 5.6 shows the percentage of utility revenue spent on electric efficiency programs in different states in 2009 and Virginia's utilities are found to have invested nearly zero percent of their revenues during that year.

Figure 5.6: 2009 Electricity efficiency program state wise spending and budgets.



Source: (Molina et al., 2010)

Table 5.3: Net utility spending in electric efficiency programs:

year	U.S	VA	CA	NY
2004	$1.4 billion	0	380 million	147.2 million
2006	$1.6 billion	$84,000	357 million	224.9 million
2007	$2.2 billion	$1,000	755 million	241.5 million
2009	$3.4 billion	$400,000	998 million	378 million
2010	$4.6 billion	$200,000	1158 million	584 million

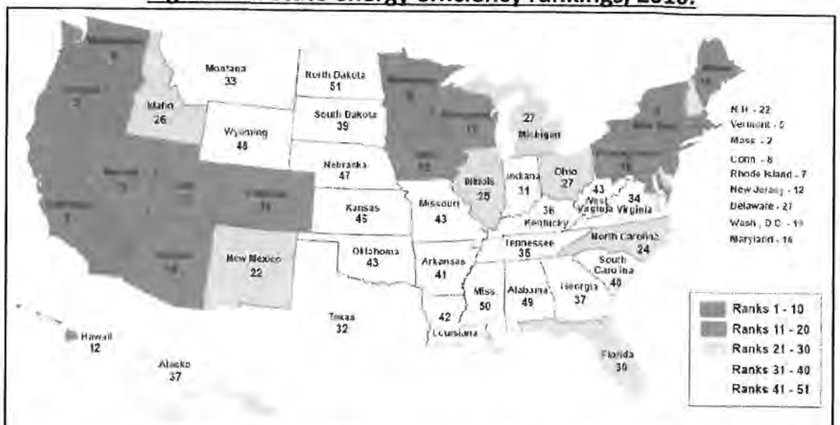
Table 5.4: Net electric savings by utilities through electric efficiency programs:

year	U.S	VA	CA	NY
2006	7.8 million MWh	63 MWh	1.9 million MWh	0.8 milloin MWh
2007	9.8 million MWh	83 MWh	3.4 million MWh	.5 million MWh
2008	10.6 million MWh	14 MWh	3 million MWh	0.47 million MWh
2009	13.1 million MWh	1029 MWh	2.3 million MWh	0.9 million MWh
2010	18.4 million MWh	677 MWh	4.6 million Mwh	1.2 million Mwh

The data shown in Tables 5.3 & 5.4 are based on the *American Council for Energy-Efficient Economy* (ACEEE) State Energy Efficiency Scorecards, corresponding to the time frame between 2006 and 2011 (Eldridge et al., 2008; Eldridge et al., 2007; Molina et al., 2010; Sciotino, 2011). As seen in Table 5.3, Virginia's net utility spending in DSM programs have been significantly low compared to the benchmark states with New York having made the highest investments among the three states. Table 5.4 shows the proportional amounts of electricity saved every year through efficiency programs and Virginia has quite apparently saved the least.

The above facts concerning Virginia easily suggest that insufficient DSM investments over long periods must have contributed vastly to the state's high consumption figures due to unaddressed inefficiencies across households. Figure 5.7 shows the ranks of different states based on their efficiency levels and efforts made to improve them. Virginia ranks 34th in the country while California and New York rank 1st and 4th respectively.

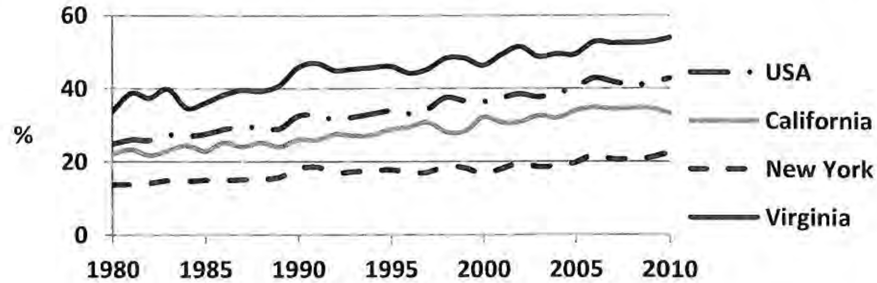
Figure 5.7: State energy efficiency rankings, 2010.



Source: (Molina et al., 2010)

5.2.3 PERCENTAGE OF RESIDENTIAL ENERGY USE FROM ELECTRICITY

Figure 5.8: Percentage of residential energy use per household from electricity, 1980-2010.



Source: (EIA, 2012b)

As described in chapter 1, the percentage of Virginia's residential energy that comes from electricity is visibly higher compared to those of the benchmark states and is also gradually rising with time (Figure 5.8). The above discrepancy among the three states may be attributed to differences that exist among them with respect to electricity pricing and energy source preferences among the states' households. As previously discussed (Figure 5.5), electricity prices are more expensive in California and New York than in Virginia. Unlike Virginia where electricity is the preferred choice of energy source among majority of households, majority of California and New York's households use natural gas for major home services which include space heating, water heating and cooking (Table 5.9). The above reasons provide a possible explanation for why the percentage of energy use from electricity among households of California and New York are lower than in Virginia. It is ultimately clear that the energy use trend amongst Virginia's households is uniquely contributing to the growth in the state's residential electricity consumption rates.

Table 5.5: Fuels used for various end uses among CA and NY homes, 2009.

Service type	Number of CA households (millions) using			Number of NY households (millions) using		
	Electricity	Natural Gas	Propane	Electricity	Natural Gas	Propane
Space heating	4.6	7.5	0.4	1.5	4.2	0.1
Primary	2.6	7.2	0.3	0.5	4.1	-
Secondary	2.5	0.9	0.1	1.0	0.3	-
Water heating	1.4	10.3	0.5	1.2	4.4	0.2
Cooking	4.8	7.8	0.3	2.3	4.3	0.4
Other	12.2	5.0	4.0	7.2	1.4	2.3

Source: (EIA, 2010)

The comparative analysis therefore makes it clear that ***square footage in housing units, household size, retail electricity prices, demand side management efforts and the percentage of residential energy use from electricity*** have hypothetically been the most influential factors behind Virginia's R.El.C trends. Policy actions will need to focus on the above aspects in order to effect positive change in managing per capita and per household residential electricity consumption rates in the state. Chapter 6 provides a conclusive hypothesis based on the results of the comparative analysis and, in doing so, answers the dissertation's primary research question:

> ***What are the sources of high per capita and per household electricity consumption in Virginia's residential sector and what has caused them to grow rapidly between 1980 and 2010, in contrast with benchmark states of California and New York?***

The chapter then concludes the dissertation with general recommendations and a brief outlook on further areas for research.

6 CONCLUSION: SOURCES OF GROWTH IN VIRGINIA'S R.EL.C TRENDS

This dissertation has applied system dynamics principles and explored the roots of increasing per capita and per household consumption in Virginia over a 30 year time period from 1980 through 2010. This trend stands in stark contrast to the benchmark states to which Virginia was compared: California and New York. In both these states, per capita and per household residential electricity consumption rates (hereafter referred to as "normalized R.El.C") are dramatically lower than those of Virginia. Moreover, the gap between Virginia's normalized consumption and the benchmark states is continuously increasing.

The dissertation initially outlined the general dynamics that drive total state residential electricity consumption and then contrasted how these dynamics, though present in Virginia and the two benchmark states, can vary across states in terms of which elements behind those dynamics dominate the scene. Although some commonalities were observed across the three states, several important differences were also identified.

6.1 COMMONALITIES AMONG VIRGINIA AND THE BENCHMARK STATES

Residents of all three states have exhibited more or less similar trends in discretionary income with increases ranging from 256% (in Virginia's case) to 276% (in New York's case) between 1980 and 2010, and with similar annual growth rates (4.7%) during this period. These trends reflect a probable growth in household discretionary income across Virginia, California and New York. The above fact, coupled with factors like a growing array of electrical appliances that have generally become more affordable over the decades, have led to increasingly greater electrical household demands; this has been a general trend among all three states.

Although technological improvements in electrical heating, air conditioning, cooking appliances, etc. have provided efficiency level gains that help reduce electrical demand, the high cost of conversion to efficiency certified appliances significantly dampens their favorable impact on total electricity demand. Since heating and cooling are the primary components of residential energy demand, a slow migration to either more efficient electric units or to other energy sources (such as natural gas) will only continue keep electricity demands high owing to inefficient consumption. Without adequate incentives to make such useful efficiency upgrades, homeowners will be slow to make substantive reductions in their electricity demand. This is partly the reason that all of the states in the study show, at best, level normalized R.El.C rates over the thirty year study period.

Another common trend observed was that the stock of ageing housing units is growing across all three states and units aged over thirty years formed the majority among these states in 2010. Although the above trend may imply that growing inefficiency levels due to ageing homes would be a subsequent commonality, greater demand side management efforts in California and New York however suggest that residential inefficiencies have been better managed in these two states in contrast to Virginia.

6.2 DIFFERENCES BETWEEN VIRGINIA AND THE BENCHMARK STATES

In 2009, Virginia homes had the highest average square footage among the three states. In addition, the average square footage of homes has increased faster in the Southern States region, where Virginia belongs to, than in the Western or North Eastern states regions which represent California and New York respectively. Perhaps most significantly, and possibly because of the impacts of many other factors, the average number of people living in a household in Virginia has decreased by about 2.2% over the 30 year study period, while the same has either remained relatively flat (New York) or increased (California) in the other states. In other words, the average personal floor space of a Virginian resident that needs to be heated, cooled and lit has increased over time thereby driving up per capita consumption needs for the respective electrical services.

For most of the 21st century, Virginians have enjoyed lower electricity rates than any of the benchmark states. Electricity has remained the cost effective energy source and also the preferred choice by majority of Virginia's households for major electrical services including space heating, cooking and water heating. The above combination of trends has resulted in electricity accounting for a major percentage of Virginia's residential energy-use unlike California and New York where natural gas is the major energy source. Moreover, the fact that households have become more affluent in Virginia has resulted in a low price elasticity of demand scenario and hence the gradual increase in the state's electricity prices between 1980 and 2010 has not had much of an impact on the ability of households to absorb greater utility bills.

Finally, investments in demand side management by Virginia's power companies have been negligible compared to the benchmark states. In 2009, the electric utilities in California and New York have spent at least 1% of their revenues to promote demand side management to decrease consumer electricity demand. Virginia's utilities, on the other hand, have spent almost nothing to promote consumer conservation and appear to be competing with West Virginia for the lowest ranking state in demand-side management efforts in the nation. The above facts give the impression that Virginia's power utilities, with a motive to attract high consumer demands, may have avoided large investments in DSM efforts in fear that it would undercut demand and lead to revenue losses. In summary, insufficient utility measures to promote efficiency and conservation amongst Virginia's households have left inefficiency levels unchecked eventually allowing wasteful increases in normalized residential electricity consumption.

Hence in Virginia, a combination of several elements has given rise to that "perfect storm" which has led to ever growing normalized R.El.C rates in the state. While some elements of this perfect storm may be present to varying degrees in the benchmark states, the particular combination in Virginia is unique when compared to California and New York. The key elements are identified as follows:

1. Increasing discretionary income, a common trend found among the three states
2. Larger homes with average floor space increasing at a faster rate than in the benchmark states
3. Fewer people per household and a declining trend in contrast to the benchmark states
4. Lowest electricity costs among the three states
5. Lowest utility efforts toward demand side management among the three states; one of the lowest ranked states in the country in terms of DSM efforts.
6. Low overall efficiency levels among households
7. Greater preference over electrical appliances for major household services which in turn contributes towards a larger percentage of residential energy use from electricity

6.3 POLICY RECOMMENDATIONS

Listed below are recommendations for policy actions focused on how per capita and per household electricity consumption rates in Virginia may be suppressed. Policy actions may be classified under three categories. These include public educational programs, governmental policy actions and power utility measures.

Public educational programs are a powerful tool that can be used to spread information and awareness among Virginia's residents. People need to be primarily educated about the various dynamics that contribute to increased household electricity consumption and greater monthly utility bills. Residents should be made aware of the different methods that can be employed to cut down unnecessary electricity consumption. These include making costly but worthwhile investments in efficiency upgrades i.e. efficiency certified appliances and building refurbishment materials. Residents must be educated about the pay back times of such upgrades and should be encouraged to make the necessary investments when possible despite the high initial costs involved. People should be made aware of the inefficiencies associated with ageing household appliances and housing units and how timely upgrades can help improve efficiency levels and save electricity. Further awareness should be raised regarding the benefits that small housing units bring in terms of electrical cost savings. Educational programs may be organized by non-profit organizations, power utility companies, etc.

Governmental policy actions may consist of incentives or tax credit programs, rebate programs and enforced regulations. Providing residents with tax credits and rebates to adopt efficiency upgrades may help increase the penetration rates of more efficient appliances and building refurbishment materials that are available in the market into consumer households. Tax credits may also be useful to encourage households to purchase newly built housing units and move from older homes. Enforcement of stricter efficiency standards for appliances and new building constructions would push the respective industries to further improve corresponding energy efficiency technologies. **Power utility measures** must focus on improvement of demand side management in the state without compromising on such efforts due to concerns over demand under-cutting. Government and third party funding may also be useful in promoting utility DSM efforts. Stricter governmental policies like establishing a required annual minimum of electricity savings can cause utilities to emphasize more on conservation through demand side management.

6.4 POTENTIAL FOR FURTHER RESEARCH

The boundaries of the current dissertation were limited by the quality and resolution of data that were available. On that note, there is still potential for future research that can further enhance current knowledge on the various aspects responsible for Virginia's residential electricity consumption patterns. Following are areas that can be explored via future research by collecting the relevant data:

1. Study of usage patterns of home electrical appliances and personal electronics by analyzing the specific usage times of various appliances. This would provide information on how much electricity is being spent monthly for various electrical home service e.g. space heating, air conditioning, etc. and possible opportunities for reduction.
2. Household decision making with regards to investments in efficiency upgrades. This would shed light on whether households are making the right choices when it comes to purchasing the right appliances or the necessary home refurbishment materials that can help in reducing household inefficiency levels.
3. To better understand the electricity pricing structure in Virginia and to determine if an increasing block pricing structure would be beneficial in reducing residential electricity consumption rates.
4. To determine the extent to which energy-source switching and the rebound effect may be contributing to the growth in Virginia's residential electricity consumption rates.
5. To analyze how pricing of other fuels influence household decisions on the type of fuel preferred for major household services like cooking, space heating, water heating, etc.
6. To develop a quantitative stock and flow model of the system using system dynamics principles.

The use of system dynamic methodology has therefore proved effective in exploring the sources of high per capita and per household electricity consumption in Virginia's residential sector between 1980 and 2010 and has helped identify the reasons behind their growth in relative contrast with benchmark states, namely California and New York. Qualitative analysis using system dynamics principles provided insight on the general dynamics that drive residential electrical consumption rates across U.S households. Further validating these dynamics with respect to Virginia and contrasting them with the benchmark states helped identify those unique set of conditions which, upon interaction, created that 'perfect storm' which inevitably caused a continuous growth in Virginia's residential electricity consumption rates. Ultimately, it has been found that a combination of economic and lifestyle factors among Virginia's residents compounded by a low-cost high-volume 'business as usual' strategy by the state's power utility sector with negligible investments in demand side management efforts have worked relentlessly to cause per capita and per household residential electricity consumption rates to rise in the Commonwealth during the three decades. The results of this study are intended to support in better management of residential electricity consumption rates in the Commonwealth of Virginia. A successful future reduction in consumption rates will help lessen pressures on the state's economy as well as the environment.

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Introduction

As the prices of crude oil rise and fall over the years as the course of world events play out, the interest in developing alternatives to fossil fuels, more specifically petroleum fossil fuels, has waxed and waned. Currently as the price of crude oil continues to rise, so does the interest in its alternatives. There are other factors at play in the development of alternative fuels, most notably environmental, but in a capitalist society such as the United States and the global market at large, economics makes or breaks products and their companies. Oil is currently the staple fuel of the global transportation sector and is so for a number of reasons. These reasons have to do with the mix of forces resulting from the geopolitical rivalries, corporate competition, social unrest, hegemonic sequence, social needs and demands, physical traits of oil and the dominant technological paradigm of the time colliding to render oil as the dominant energy source for transportation purposes (Podobnik).

To begin to explain how a new energy resource that at the time was more expensive than the dominant energy source of coal will require a journey into world history. Oil was an upstart industry in the United States prior to the American Civil War. John D. Rockefeller was starting to build his empire through his various shrewd business practices when war broke out between the Northern States and the Southern States. Since petroleum at the time was refined mostly into kerosene to burn in lamps, the war drastically increased need for it as lamp oil to illuminate camps as well as machinery lubricants (Podobnik). After the war Rockefeller continued to consolidate his business empire, but the advent of electricity threatened to extinguish his lamp oil business. His fortunes and the fortunes of the oil industry in general were changed greatly with the invention of the internal combustion engine. This new technology enabled continued demand for oil in what would become the modern transportation sector cornerstones of automobiles and planes. The internal combustion engine also began to replace the steam engines of ships and trains as coal became viewed as an unreliable source of energy due to increasing labor militancy disrupting supplies and causing unfavorable spikes in prices. The relative cleanliness of oil combustion as well as it being a liquid only helped it overtake the dominant coal industry of the previous century. These factors played a major role in causing the British Royal Navy to switch their fleet from coal to oil powered vessels despite a lack of domestic petroleum reserves prior to World War I. This influx of steady funding and military technical knowledge allowed the oil industry to firmly establish itself in the transportation sector and work out the kinks in the technology required to burn oil. To make up for the lack of domestic reserves, the British relied upon foreign reserves that they had established control of around the world in the previous century including Persia or modern day Iran (Podobnik).

With the outbreak of World War I, the importance of oil in modern warfare was fully manifested with the advent of the widespread use of tanks, trucks, automobiles, airplanes, and the more tactically advantageous oil powered battleships. After World War I, the allies carved up the world, including its known oil reserves, between the victors, making sure that the members of the Central Powers were excluded. This exclusion and harsh treatment of the Central Powers eventually led to the rise of the Axis Powers and World War II. Unfortunately for the Axis Powers, the Allies control of the world oil reserves plagued them throughout the war, eventually leading to their defeat. Examples include: Hitler's invasion of the Soviet Union seeking the Caucasian oil reserves; Japan's invasion of Korea, Manchuria and the Dutch East Indies seeking oil reserves, the last invasion prompting the Japanese to preemptively bomb Pearl Harbor leading to U.S. entry into World War II; conflicts over the Middle East and other oil producing regions; and failures of Axis offenses and maneuvers such as the Battle of the Bulge (Podobnik). Victorious after World War II, the allies did not wish to be left strategically vulnerable due to a lack of petroleum reserves and needed the energy to rebuild the world devastated by the war. This need of petroleum energy for economic and military post-war build up by both of the emerging super-powers resulted in the cementing of oil as the foundation of modern civilization. As the oil system was expanding with in the Western and Eastern spheres of influence, the coal system was in decline. Coal was the fuel of the previous century and the labor militancy of its workers nailed the coffin shut on what was once coal's dominance. As stated previously, miner's strikes at times of critical national importance, including global conflict, forced coal consumers ranging from national governments to the average citizen to reconsider coal as an energy source. The concessions given to the miners, while justified, reduced the competiveness of coal, reducing it to a fuel of the past that still lingers on out of necessity (Podobnik).

With coal thrown to the way side and a prosperous oil system on the rise during the peak of the Cold War, prosperity in the West seemed limitless. The West had brought under its control, through a combination of economic and military power, a variety of oil producing countries. This situation changed drastically after the U.S. defeat in Vietnam. Where the United States was once viewed as an undefeatable force to be reckoned with, this was no longer the case. This loss of respect and general U.S. military withdrawal from the world built up social unrest throughout the Western oil system. This unrest culminated in the reaction to the results of the Israeli Six Day War, in which Israel defeated the Egyptian, Syrian and Jordanian forces simultaneously and swiftly. Arab anger intensified at the United States due to their unwavering support for Israel and the United States along with the Dutch imposed an embargo on Arabian oil. Nationalizations of oil companies around the world and the rise of the Organization of Petroleum Exporting Countries (OPEC) to international importance due to their price manipulation of oil soon followed. Later on in the same decade the Iranian Revolution ousted the pro-American Shah and replaced him with a religious theocracy that was openly hostile to the United States, cutting off oil exports to the United States and setting the precedent for revolution in the oil system. The Iran-Iraq war that soon followed continued to highlight the influence of Middle Eastern conflict on Western economies through the volatility induced on oil markets (Podobnik). Even with the fall of the Soviet Union and the decade of prosperity that followed, the spillover of oil politics from oil supplying nations into the oil consuming nations of the West opened the next decade with the September 11, 2001 terrorist attacks. The conflicts in Afghanistan and Iraq that soon followed only intensified the volatility of oil markets and continued to underscore the power the oil suppliers had over the Western world. With the current tensions in the Middle East, most notably Iran and Syria, as well as the latest September 11, 2012 attacks on United States embassies throughout Middle Eastern countries, the unrest throughout the global oil system is alive and well in the year 2012. The global oil system, like the global coal system prior to the last major energy shift, is suffering from decades of supplier side unrest. While this unrest may or may not be justifiable, this unrest none the less forces reconsideration of the current oil system and focuses efforts on finding the next major energy source to alleviate current supply disruptions and the inequalities that plague the current global energy system.

With an explanation for why oil is the dominant energy resource, as well as a brief discussion of the geopolitical forces currently at work in the oil system complete, a discussion of the environmental concerns due to oil is necessary. The first and most concerning environmental issue related to oil or fossil fuels in general is global climate change, which most scientists agree is happening. Since scientists as a rule are a skeptical group of people, here is summary of what they think. First, scientists agree that since the industrial revolution, humans have dumped excessive amounts of CO_2 into the atmosphere, which is known to be a greenhouse gas, or a gas that tends to raise the temperature of the planet. From there, the scientific community says that its very likely that this increase in CO_2 and temperature, which may possibly, although highly unlikely may not be related to CO_2 emissions, that has occurred since the industrial revolution will likely cause global climate change (EPA Climate). This matters to this discussion on oil because oil is currently the dominant fossil fuel and a major contributor of anthropogenic CO_2 to the Earth's atmosphere. Therefore drilling for more oil or carbon underground and bringing it to the surface to be released into the atmosphere will only worsen this problem if a global CO_2 increase induces a global temperature increase which in turn induces more global climate change.

The other direct environmental problems related to conventional vertical oil drilling are: Noise pollution from drilling, environmental damage from the building of infrastructure around the oil well, the potential for oil spills, presence of industrial communities, disruption of animal migratory paths, accidental animal kills during construction and operation, presence of roads and road construction disrupting the natural ecosystem, spills of other chemicals besides oil, and environmental damage caused by the presence of other supporting infrastructure (Papadakis). While these threats are major, they are still minor compared to the more modern deepwater drilling or hydrolytic fracturing of "tight" shale oil. The affect of wide scale environmental devastation from ocean spills such as Deepwater Horizon and Exxon Valdez is due to the oil's ability to cover large areas of ocean with minimal volume. The environmental effects of hydraulic fracturing are still under investigation by the EPA (EPA Fracking). Conventional drilling disturbs the environment, unconventional drilling disturbs it even more, yet as stated above, it is the foundation of modern civilization, so an outright ban without a viable alternative is almost laughable, underscoring the complexities of the problems associated with oil.

There are also a multitude of economic and social issues surrounding the use of crude oil as well. While economic issues are a typically viewed as a separate set of issues, they directly affect and give rise to the social issues surrounding this resource. To begin with economics, primary energy supplies are fundamental to the modern global economy. No matter what business one is in, from manufacturing to service sector, everyone uses energy and is affected by it. To narrow the focus since this is a conversation about oil and the transportation sector, every business must move its people around and its product to the consumer one way or another. Since oil dominates the transportation sector, the price of oil plays directly into the cost of everything from non-essentials such as toys to necessities such as food. This causes a ripple effect through the economy as the price of oil increases or decreases. This ripple effect is positive when the price oil decreases and is negative when the price of oil increases. As the impact of the price of oil ripples through the economy, the social impacts start to become apparent. These impacts range from the lack of affordable and convenient transportation to the increasing cost of everyday goods such as food. The bottom line of all this being that as the price of oil increases, the cost of doing everything increases, decreasing the buying power of the consumer and handing what money the consumer does have to the oil suppliers, resulting in an economic nightmare if prices reach dangerous levels. There are institutions in place to protect against such an economic nightmare, so there is no need to panic, but do not underestimate the effect that the price of crude oil has on the economy and the daily life of the consumers that have no choice but to absorb the price increases.

To completely comprehend the problem of petroleum, there is a social impact that is often neglected at argumentative peril: The love of automobiles. While this love is most notably in the United States, this love has spread all over the world thanks to global westernization. Everyone likes the ease, convenience and fun of driving their own vehicle. This is so much the case that even though that roughly 33,808 people died in automobile accidents in the United States in 2009, people are still driving (LaHood USDOT). To further drive home the love of automobiles in the United States, think of the fundamentals of the American dream and way of life. This generally includes a job, a house with a white picket fence to be stereotypical and most relevant of all to this conversation: At least one automobile. The automobile is a cornerstone of American culture and to say that it can be removed completely overnight without replacing it with something better is naive. Americans love their cars and as a rule are dependent on them to carry out their everyday life. To elaborate, while most of Americans do live in the city, a large minority do live in the country where a public transportation system is non-existent or impractical if best due to the vast distances that Americans in the country are required to travel.
While there are oil consumers in every country, and the above economic and social impacts affect the first world consumer just as much as the third world consumer, there are also a number of social impacts involved on the supplier side of the oil system. While most of this is wrapped up in geopolitical issues, the geopolitical issues exist due to these social factors. The most noticeable and unfortunate social impact is the unequal distribution of oil wealth. As a rule, it is concentrated in the hands of a small ruling elite who stabilize the country enough for the extraction of oil and other resources. The most notable case of where this system broke down was Iran. The Shah spent money on himself and his peers, but failed to provide fully for his people. As his expenditures became more extravagant and the measures to maintain order more severe, the anger of his people also grew. Finally, the people revolted while the Shah was out of the country and a religious theocracy took his place (Podobnik). Instead of spreading enlightenment to Iran, the West spread inequality and oppression, causing the Iranian people to put their hope in a religious leader who despised the West. Their hatred of the West now threatens to destabilize the entire oil system with the threat of a shutdown of the Strait of Hormuz, not to mention the threat of nuclear weapons proliferation from their reactor technologies. While Iran is only one example of the inequalities created by the oil system, there are many more examples throughout the Middle East and the world. The oil system has exacerbated poverty and inequality in these countries. These people distrust the West and with the Arab Spring, they are now in power. What is done is done, groups of these people now wish to destroy the West and what it stands for by any means possible. While there is little hope in healing the wounds of both sides, an alternative to petroleum would be a start.

Since oil is causing all of these problems, something should be done to address them, but before one goes about blindly making changes, that person should first completely understand why oil is the dominant form of energy in the transportation sector today and while a brief history of the rise of oil was given above, the following lists the main hurdles to overcome if a viable replacement is to be found and implemented. First and foremost conventional oil is currently the cheapest option out there. In a capitalist system, the highest quality product for the cheapest price typically wins out, currently alternatives to oil do not meet this criteria. Second, the physical characteristics of oil such as its high energy density in a liquid form make it appealing to use as a transportation fuel. This is why oil is used in automobiles, trains, ships and planes. To build on the appealing physical characteristics of oil, the established technological paradigms of the internal combustion engine, jet engine and all of the infrastructure surrounding oil contributes to its widespread and dominant use. These factors combine with the previously mentioned geopolitical, corporate, hegemonic and social forces surrounding the oil industry to make it the dominant and in the case of the airplane, mono-fuel of the transportation sector. This current dominance means that oil is probably going to be around for many more years, for as in the case of coal, even though the dominant form of energy shifted away from coal to oil, the consumption of coal continues to climb (Podobnik).

With this background knowledge of why there is a problem with using petroleum and why it is the dominant transportation fuel established, now is the time to look at what can be done to solve the problems surrounding oil. To start the conversation about what can be done to solve the problems surrounding oil, a look at the primary energy consumption by source and sector of the United States, the world's number one consumer of petroleum, is necessary to quantify the extent of the problem. The United States Energy Information Administration has prepared a graph for 2010 compiling the desired information and is shown below.

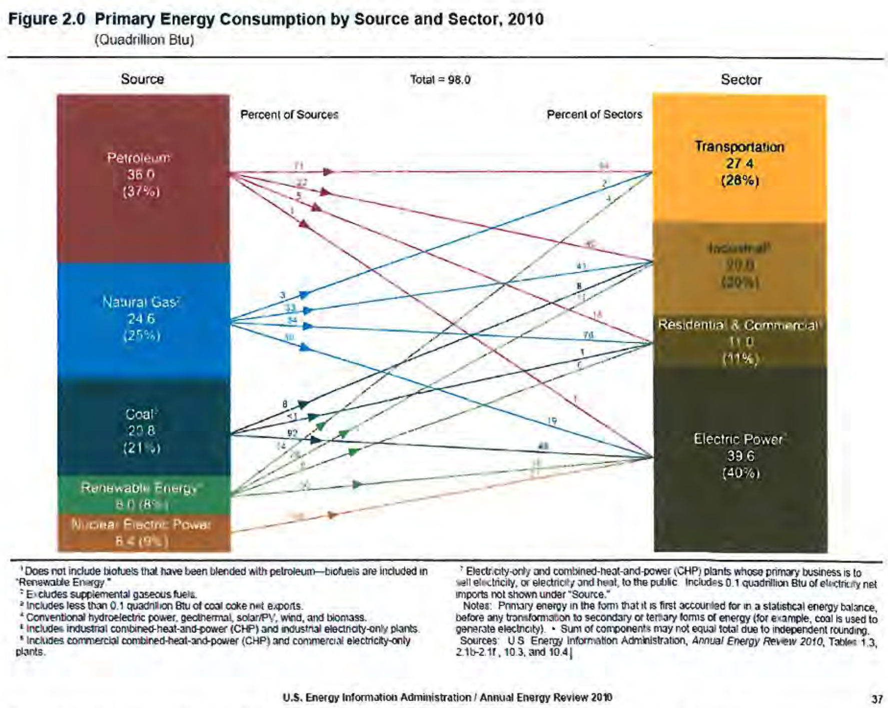


Figure 1: Graph of United States Primary Energy Consumption by source and sector for the year 2010. Notice that 71% of the United State's petroleum consumption is in the transportation sector, which it comprises 94% of. Source: US. E.I.A. Annual Energy Review 2010.

The above graph shows that in 2010 71% of the petroleum used in the United States was used by the transportation sector and that 94% of the transportation sector was powered by petroleum. The alternatives to petroleum that constituted the remaining 6% that met the transportation sector's fuel needs were Natural Gas with 2% and Renewables with 4%. Notice that coal and nuclear power did not contribute to the energy consumption of the transportation sector. To be fair though, electricity in this graph is an end use sector and not a source. With the current and dominating status of the relationship between oil and the transportation sector established and quantified, solutions to the problems surrounding oil can now be discussed.

Increase Drilling

The first logical solution to the problems caused by high oil prices would be drilling for more oil. Under the laws of supply and demand, as supply increases and demand stays the same, the price goes down. Unfortunately in the case of oil and energy, the world population is increasing as well as modernizing and therefore demand is constantly increasing. Therefore any increase in supply must outpace the increase in demand for it to have a real affect on oil prices.

Since modern civilization depends on cheap oil, anything that is a threat to oil remaining cheap is typically viewed with outright skepticism and denial if no real alternative is offered, as it generally is not. This is why the environmental arguments mentioned previously fail to woo large groups of consumers to the anti-conventional-petroleum or more generally anti-fossil-fuel mindset. So for now, this skepticism about the existence of a petroleum problem will be addressed with US oil reserve and resource data from the Energy Information Administration and while it only shows oil that is currently allowed to be drilled for, it still illustrates the United State's lack of a long term domestic supply that will last for generations.

Table 1: Table displaying US Proven Oil Reserves, US Inferred Oil Reserves and US Undiscovered Oil Resources in Billion Blue Barrels for non-banned areas and how long they would last in years if the US was cut off completely from foreign oil at current production and consumption rates. For the consumption values, production was assumed to match consumption, which it does not, to show how much oil the US actually consumes and that the US is dependent on foreign reserves by default. Sources: EIA Oil Reserves, Production and Consumption.

Oil Reserves (Billion bbl)				
	US Proven Reserves	US Inferred Reserves	US Undiscovered Resources	Total of Official EIA Estimates Based Off of Non-Banned Reserves
Non-Prohibited Oil Reserves and Resources	20.6	62.5	135.8	218.9
Years of Available Oil (At Current Rates)				
Years of Available Oil At Current Production	10.0	30.2	65.6	105.7
Years of Available Oil Assuming Production Meets Consumption	2.9	8.8	19.1	30.7
US Annual Production	2.07		US Annual Consumption	7.12

While we do have a fair amount of oil resources, our conventional reserves are small and will continue to decrease as new discoveries decrease and consumer demand for oil increases. As conventional supplies decrease, the necessity of finding other unconventional supplies of or alternatives to oil becomes apparent. While at current production rates, if the United States were cut off from global oil supplies, the United States does have over a decade of proven reserves and a century of oil resources, if it were possible to recover them, see Table Y. If this unlikely scenario were to happen, current reserves only buy time until domestic oil runs out. Despite this scenario being unlikely, it highlights how small the United State's domestic oil reserves really are when compared to domestic rates of production and consumption. Notice that if the US produced as much oil as it consumed, this amount of time would decrease to just less than three years of conventional supplies and thirty years of resources. While drilling for more oil is only one potential option to maintain modern society without any replacements for oil, as domestic oil reserves dwindle, the size of the reserves in the table would most likely increase or remain stagnant as areas that were once restricted to drilling are opened up out of necessity. As these less conventional alternatives to conventional oil become more mainstream and more areas of protected land are opened up, the chances for environmental catastrophe increase dramatically, not to mention that nothing is still being done about global warming.

Oil Sands

The first of these non-conventional forms of oil is oil sands. Oil sands are currently supplying the US with 500 million barrels of oil a year, making Canada the US's number one oil supplier and the country with the 3rd largest proven oil reserves (Alberta Energy and EIA Oil Sands). While this is a way of producing oil, it is not as economically efficient or environmentally friendly as conventional oil. Oil Sands suffers from a rash of environmental problems, besides being a form of oil, such as: Conventional ex-situ open pit (strip mining) and steam injection in-situ extraction techniques, the large amounts of water required to separate oil from the sands once extracted and being a worse emitter of CO_2 than conventional oil (EIA Oil Sands). While this form of unconventional oil is on the market and becoming conventional, oil shale is not even viable yet (EIA Oil Shale).

Oil Shale

To clarify between the terms shale oil and oil shale, shale oil is oil extracted using hydro-fracturing to increase the yields of oil fields that under conventional methods were not economically viable anymore, if ever at all (EPA Fracking Process). Oil shale is a rock that contains oil like substance called "kerogen" that in raw extracted form can be conventionally burned in bulk like coal. To turn oil shale into a petroleum product, it must undergo gasification, which is conventionally performed above ground after extraction using methods similar to coal. There are various proposed methods to perform gasification in situ (underground) but while they avoid the economic and environmental costs of conventional mining and transportation of a bulk product, they come with their own set of concerns (EIA Oil Shale). The surface retorting or gasification of oil shale underground both have the potential to pose numerous environmental problems in the areas of: Land use due to surface mining, air quality due to refining plants, climate change due to increased CO_2 emissions, water quality due to leeching toxins into the

Colorado river's drainage basins and a large increase in water consumption from the Colorado river, which already no longer reaches the sea (UCLO).

Coal Liquefaction

Coal liquefaction is the process of turning coal into a form of crude petroleum which is then typically refined into gasoline or diesel fuel. Considering that at current consumption rates, U.S. coal reserves will last for another 250 years and that the U.S. has the largest coal reserves in the world, this is another realistic source of petroleum as conventional supplies diminish. The problems with this technology are: It is not economically viable with low petroleum prices, exposing it risks arising from price volatility; not environmentally friendly due to the expansion of coal industry, does not address global climate change and uses large amounts of water; and finally since it encourages coal production, this technology raises social issues due to the stigma of using coal. Since this technology is relatively established compared to other alternative fuels, there is even a plant operational in South Africa, this technology has been a stand by emergency fuel in case of a global crisis. One final consideration is necessary for evaluation of this technology: If this technology were to be scaled up to actually supply petroleum on a national or even global scale, the rate of decline of the world's coal reserves would rapidly increase, highlighting the lack of sustainability of this technology (Miller).

Propane and Natural Gas

Propane and natural gas are available as transportation fuels in the forms of liquefied petroleum gas (LPG or Propane), compressed natural gas (CNG) and liquefied natural gas (LNG). Propane is stored on board the vehicle in a tank pressurized to about 150 PSI. Propane has a lower BTU rating than gasoline, but burns cleaner, increasing engine life and is better for the environment (Propane). CNG is clean burning and is domestically produced. CNG is stored on board the vehicle at pressures ranging from 3,000 to 3,600 PSI and is used in light, medium and heavy duty applications (Natural Gas). LNG is also clean burning and is domestically produced. LNG is produced by super-cooling purified natural gas to -260 ^{o}F and must be stored in double-walled, vacuum-insulated pressure vessels. Due to the higher energy intensity of LNG, it is typically used in longer range truck applications. LNG is typically used in medium and heavy duty vehicles (Natural Gas), General Motors™ is already producing vehicles that run on LPG and CNG for the general market (GM).

Propane and natural gas is still relatively small in use as a transportation fuel compared to gasoline, but with the decrease of natural gas prices in the U.S. due to the increased supply from hydraulic-fracturing (fracking), this fuel source will likely grow in the very near future. While this fuel is domestic, hydraulic-fracturing is still currently under investigation by the E.P.A. (E.P.A. Fracking). Also while the combustion of natural gas emits less carbon dioxide than conventional fossil fuels, it still emits carbon into the atmosphere. Another factor to consider is that methane, if unintentionally released into the atmosphere is a much more potent greenhouse gas than carbon dioxide. Natural gas appears at this point to be a viable alternative that will have to be phased in as a transportation fuel. While natural gas is certainly a step in the right direction, fossilized natural gas should not be considered the final answer from a sustainability stand point.

Methane Hydrates

Methane hydrates are solid crystals that are typically made of water in the form of ice that have natural gas, along with other gasses, trapped inside of them. There are vast deposits of them on the ocean floor with some theoretical estimates coming in at 270 million trillion cubic feet of natural gas (Hydrates 2). This greatly expands the current global naturals gas reserves of 13,000 trillion cubic feet (Hydrates 2). The potential here for relatively sustainable energy (from a pure energy perspective) is real. With a natural gas infrastructure already on the rise in the U.S. in all energy sectors, a new supply this substantial is almost like a dream come true, but as with all energy systems, there are drawbacks. These drawbacks include the need for more research and development to bring this resource to light, the potential for environmental catastrophe due to the collapse of the ocean floor due to disturbing these volatile compounds and finally the large scale accidental release of methane into the atmosphere (Hydrates). A future with almost unlimited energy may be possible with methane hydrates, but this resource should be pursued carefully due to the reasons stated above as well as the continuing emission of fossilized carbon into the atmosphere, increasing the impact of global warming.

Hydrogen

Hydrogen, unless derived from an organic source such as a fossil fuel or even a biomass, is more or less a form of energy storage. If however, hydrogen is viewed as a more efficient extension of any one fuel, then it becomes more than that. This is achievable through fuel cell technology, but for this technology to come about more research and development is required to make this technology more practical and economical. Hydrogen also has issues in storage and transport due to its volatile nature, but this typical of any fuel and can be overcome through good engineering. Hydrogen has been the fuel of the future for some time now and it still can be with good research and development, but for now, it remains the fuel of the future (Hydrogen Impact).

Electric Vehicles

Electric vehicles are another up and coming alternative to conventional transportation fuels. With the advent of plug in hybrids such as Chevrolet's Volt™, electricity could become a player in the transportation industry in the very near term, in a sense similar to natural gas. While this is great, the technology is not fully mature, leaving it full of kinks and making it more expensive. Another consideration with electricity, is that it, like hydrogen, is a form of energy storage, also known as an energy carrier, and the impact the electric vehicle has on the environment and society depends on what the vehicle is plugged into. Most power plants in the U.S. are still coal and while natural gas is gaining an edge over coal, it has issues that were discussed earlier. Nuclear power suffers from economic barriers and a social stigma due to the fact that things do not go bad often, but when they do, it is really bad. Solar and wind electricity are currently what is currently viewed as the greenest, but the power output of these devices is wanting. As with natural gas, electric vehicles are a step in the right direction and should experience rapid growth in the very near future. Their lack of direct emissions makes them appealing for use in cities and if the technology is developed to maturity, these vehicles could have a positive impact on society and the environment (Electricity).

Biodiesel

At the World Exhibition in Paris in 1900, Rudolf Diesel debuted an engine that ran on peanut oil. While diesel fuel derived from petroleum quickly took center stage, the modern diesel engine remains flexible and capable of running on esters derived from various vegetable oils, commonly referred to as biodiesel. But, mainly due to economics as well as a lack of scalability due to land use constraints, biodiesel remains viewed as a petroleum fuel additive in the typical forms of B2 and B20 or an emergency petroleum fuel replacement in the form of B100 in times of crisis (Knothe).

Algal Biodiesel

The Aquatic Species program, funded by U.S. department of Energy, researched from 1978 to 1995 ways of extracting energy from algae. In the later years of the program their studies focused on extracting lipids from algae to convert to biodiesel. This is one of the many potential ways to use algae as a fuel source. Algae can grow in fresh, brackish and saline environments. They require sunlight, carbon dioxide, a stable growth medium and nutrients essential to their growth. Algae come in the forms of macro-algae, micro-algae and blue-green photosynthetic bacteria. Macro-algae from a fuel perspective are mostly made of carbohydrates and micro-algae while containing carbohydrates, can have a high lipid content, reaching up to 50% of cell mass in some species. Since micro-algae are single celled organisms and can therefore double on a daily basis, their potential lipid output is huge if managed carefully. The potential use of algae to generate lipids for biodiesel is huge and is currently being looked at by companies such as Exxon Mobil™, Solzyme™ in partnership with the Department of the Navy, Sapphire Energy™, along with several other start ups. There are of course technical hurdles in the path of the development of this fuel resource, but that is what scientists, applied scientists and engineers are for. Algae are versatile and unlike land-based crops such as soy or rapeseed (canola), they can be grown in bodies of water, such as the ocean, which potentially could resolve the issue of land use considerations (DOE Algal Roadmap).

Methodology

The primary objective of this algal bio-fuel research project was to research and overcome the complex hurdle of harvesting that is currently in the path of an economically viable, resource abundant, and sustainable algal bio-fuel operation that potentially one day could meet global and domestic energy demands. In order to accomplish that, the project was been subdivided into multiple parts and to complete these parts of the project the following materials were required:

Part A: Setting up laboratory for algae growth on a harvestable scale

- Algae Cultivation Chambers
    - Algae Grow Racks (2)
    - Aquarium
    - Tub (4)
    - Heater and Thermostat (3)
    - Insulation

    - Fluorescent Grow Lights (8)
    - 600 Watt Hydroponic Light Fixture, Ballast, Cooling Fan and Duct
    - 1000 Watt Hydroponic Light Fixture, Ballast, Cooling Fan and Duct
    - High Pressure Sodium Grow Bulbs (2)
    - Metal Halide Grow Bulbs (2)
    - Circulation Pump
    - Air Pump (4)
    - Air Hoses
    - Air Gang Valves (4)
    - Air Stones (20)
    - Thermometer
    - Light Meter
- De-Chlorinated Tap Water
- Instant Ocean™ Salt Mix
- Kent Pro Culture Parts A & B™ Fertilizer Solution or other comparable nutrient source
- Algae Strains of Botryococcus Braunii, Nannochloropsis, Dunaliella and any other desired strains
- Stirring Rod
- 8 to 16 1 Liter growing vessels
- Proper Personal Protection Equipment

Part B: Development of culture condition testing curves to monitor growth

- 1000 mL beakers with 50 mL intervals (2)
- Distilled Water
- Instant Ocean Salt Mix™
- ATC Portable Refractometer
- Micropipette
- De-chlorinated tap water (set out for several days)
- Reef Master Test Kit (API, Aquarium Pharmaceuticals) that included:
    - Nitrate
    - Phosphate
    - pH tests
- Microsoft Excel™
- Scooper
- Kent Pro Nutrient Parts A & B ™
- Scale (Denver Instrument XL-3100)

Part C: Grow Algae on a harvestable scale and monitor conditions

- Materials required were the same for those required in Parts A & B

Part D: Calculation of Solar Drying Algae Harvesting Feasibility

- Assume:
    - Incident solar radiation (insolation) of 400 watts per square meter

- Specific Heat of Water of 4186 Joules per kilogram-Kelvin.
- Latent Heat of Vaporization of Water of 2.26 mega-Joules per kilogram

- Calculator

Part E: Testing Feasibility of using a Centrifuge as an Algae Harvester

- Algae Cultures of Nannochloropsis and any other desired strains
- Saltwater growth medium (controls)
- Centrifuge
- Tape and Marker
- Stopwatch
- Proper Personal Protection Equipment

Part F: Designing, Building and Testing Feasibility of Sonication Algae Harvester

- Algae Cultures of Nannochloropsis and any other desired strains
- Saltwater growth medium (controls)
- Sonicator (Sonifier ® Cell Disruptor 350 Branson Sonic Power Company)
- Test tubes or sample vials
- Tape and Marker
- Stopwatch

Part G: Designing, Building and Testing Feasibility of Ultra-Violet Algae Harvester

- Algae Cultures of Nannochloropsis and any other desired strains
- Saltwater growth medium (controls)
- 9 Watt Coralife Turbo Twist 3x UV Sanitizer™
- 1/2" I.D. Clear Tubing
- 3/4" I.D. Clear Tubing
- Water Pump with 1/2" or 3/4" outlet
- Flow Rate Adjustment Valve
- Tubing Clamps
- Support System to Hold 9 Watt Coralife Turbo Twist 3x UV Sanitizer™
- Intermediate UV Harvesting System Water Wash
- Information on the published amount of UV radiation required to kill desired algae strains
- Manufacture's Manual of 9 Watt Coralife Turbo Twist 3x UV Sanitizer™ to determine the proper kill flow rate of each algae strain.
- 1000 mL beakers with 50 mL intervals (2)
- Graduated Cylinder
- Test tubes or sample vials
- Stopwatch
- Tape and Marker
- Proper Personal Protection Equipment

Part H: Designing, Building and Testing Feasibility of Hydro-Cyclone Harvester

- Algae Cultures of Nannochloropsis and any other desired strains
- Saltwater growth medium (controls)
- Internet
- Hand Drawing Tools
- Standard 8.5" x 11" copy paper
- Microsoft Excel™
- Solidworks™
- 3-D Rapid Prototyping Printer
- 3/4" tubing (~10 feet)
- 7/8" tubing (~4 feet)
- Tubing clamps
- Duct tape
- Pump (Country Cottage Model CC210)
- 25 mL sample vials
- Algae cultures
- Ladder
- 5 U.S. Gallon Bucket
- Tap Water
- Tape Measure
- Calculator
- Tape and Marker
- Shop Air system (~120 to 140 PSI)
- PVC pipe (~10 feet, comprised pressurized system)
- Valve to hose connections (Pressurized system to Hydrocyclone hose)
- Air system connections (Air system to pressurized system)
- Hemacytometer
- Microscope
- Ethanol (70%)
- Proper Personal Protection Equipment

Part I: Designing, Building and Testing Feasibility of Electro-Flocculation Algae Harvester

- Algae Cultures of Nannochloropsis and any other desired strains
- Saltwater growth medium (controls)
- Wire Electrodes of:
    - Electrical Copper
    - Welding Aluminum
    - Welding Steel
    - Steel Rebar
- Sample Vials (25 mL)
- 9 V battery
- Variable Power Supply

- Expendable Connecting Wires
- Beakers to Perform Initial Testing
- Erlenmeyer Flask
- Rubber Stopper
- Vinyl tubing and clamps
- Vacuum pump
- Hot plate
- Kiln (Max of 200 C)
- Whey boats for drying
- Tub or Aquarium or for Scale Up
- Thorough Understanding of All Electro-Chemical Reactions to be Tested
- MSDS on all potential chemicals used or produced
- Proper Personal Protection Equipment

Part J: Determining Energy Content of Conventional Lipid Extraction

- Healthy Nannochloropsis Algae Culture (salt water species)
- Refractometer
- Hexane solvent
- Explosion Proof Blender
- Plastic graduated cylinder
- Glass graduated cylinder
- Fan
- Glass beakers (5)
- Micro-pipettes
- Laboratory Scale (Denver Instrument XL-3100)
- Glass Petri Dishes (5)
- MSDS on all potential chemicals used
- Proper Personal Protection Equipment
- Bomb Calorimeter (see **Part N)**

Part K: Evaluating Isopropyl Oil Extraction Method to determine its scalability and feasibility

- Wet Electro-flocculated Nannochloropsis Algae Mass
- Dried Nannochloropsis Algae Mass
- Isopropyl Alcohol (70% Medical Grade)
- Erlenmeyer Flask
- Rubber Stopper
- Coffee Filters
- Funnel
- Beaker
- 25 mL sample vials

- Whey boats for drying
- Proper Personal Protection Equipment
- MSDS's on Chemicals used

Part L: Determining the Energy Content of the Dried Algae Using the Bomb Calorimeter

- Bomb Calorimeter
- Graduated Cylinder (1000 mL)
- Water
- Fuse Wire for Bomb Calorimeter
- Pressurized Oxygen Supply
- Digital Thermometer with Temperature Probe
- Laboratory Scale
- Whey boats for weighing samples
- Brown Paper Towel
- Dried Algae Mass
- Proper Personal Protection Equipment

Part M: Solvent Emulsification Lipid Extraction of Nannochloropsis Algae

- Healthy Nannochloropsis Algae Culture (salt water species)
- Refractometer
- Hexane solvent
- Emulsification Device (includes valves, tubes, pump, etc.)
- Volt-meter
- Amp-meter
- Plastic graduated cylinder
- Glass graduated cylinders (3)
- Stopwatch
- Algae Inflow Vessel (At least 1 Liter)
- Glass beakers (2)
- 5 gallon bucket of water
- Micro-pipettes
- Laboratory Scale
- Glass Petri Dishes (5)
- Proper Personal Protection Equipment
- Bomb Calorimeter (see **Part N)**

Part N: Determining the Energy Content of the Extracted Oil Using the Bomb Calorimeter

- See **Part L** but placed algae lipids instead of entire algae mass into bomb calorimeter

Part O: Converting the extracted algal oil into Biodiesel

- Extracted Algae Lipids
- Methanol
- Potassium Hydroxide (KOH)
- Graduated Cylinder
- Sample Vials or larger safe mixing container
- Proper Personal Protection Equipment

Part P: Determining the Energy Content of the Algal Biodiesel Using the Bomb-Calorimeter

- See **Part L** but placed algae biodiesel instead of entire algae mass into bomb calorimeter

Part Q: Growing enough algae to obtain a gallon of raw lipids for the Senior Symposium

- Most Hardy, Reliable and Productive Algae Strain (Nannochloropsis)
- 250 Gallon Pools for culturing(2)
- See **Parts A, B and C** for other materials required for algae cultivation
- Proper Personal Protection Equipment

The procedures for executing the multiple parts of this project are listed below:

Part A: Setting up laboratory for algae growth on a harvestable scale

1. Construct grow rack to provide a stable and controlled environment to cultivate algae. Made sure that the temperature was held constant, the lighting was intense enough and the conditions of the water were monitored and kept at each algae species' optimal growing conditions.
2. Inoculated algae cultures by adding tap water in a similar quantity to the volume of algae medium that would inoculate this new medium to four of the 1 Liter growing vessels and letting them sit overnight to allow the chlorine to evaporate and the water to warm up.
3. The following day, mixed in the required amount of Instant Ocean™ salt mix to obtain a concentration similar to that of sea water for two of the vessels. Mixed in the required amount of salt mix to obtain a concentration similar to that of brackish water for one of the vessels. For additional algae species prepared grow vessels with proper salt concentration and water conditions for those species. Added the recommended amounts of Kent Pro-culture Parts A & B™ fertilizer solution to all of the growth vessels. Stirred the growth mediums of all growth vessels well.
4. Added generous amounts of each algae strain to its proper prepared growth vessel. Nannochloropsis and Dunaliella were inoculated in the seawater vessels, Botryococcus Braunii was to be inoculated in the brackish water vessel and the Chlorella was to be inoculated in the freshwater vessel. For additional algae species added species to the grow vessels prepared for them. Placed growth vessels on grow rack to grow to maximum culture. Repeated above procedure every week to sustain culture growth throughout course of project.

5. Constructed high intensity grow light system with tanks underneath it to provide a stable and controlled environment to cultivate algae. Made sure that the temperature was held constant, the lighting was intense enough and the conditions of the water were monitored and kept at each algae species' optimal growing conditions.
6. Prepared growth mediums and inoculated strains for high intensity light growth in similar manner as described in steps 2 through 4. Placed these strains under high intensity lights. Expected most of the cells for each strain to not adapt to the high light, if they did adapt, they were strong and good algae. These algae were then used for outside algae cultivation in direct sunlight once the cultures were expanded to a well sized volume.

Part B: Development of culture condition testing curves to monitor growth

1. Salinity Curve:

   i. Began to construct salinity vs. Instant Ocean™ concentration curve by calibrating the refractometer with distilled water (Set it to zero when using distilled water).
   ii. Measured the salinity of the de-chlorinated tap water. Recorded in Excel™.
   iii. Filled a beaker with 200 mL of de-chlorinated tap water. Added 1 gram (measured mass on scale and recorded in Excel™) of Instant Ocean™ and recorded salinity. Added another measured gram and recorded the salinity. Repeated until 12 grams of salt mix has been added. Plotted the results on a scatter plot and fit a Trendline™. Used this to figure out how much salt needed to be added to a growth medium or culture on based on the volume to obtain the desired salinity.
   iv. Cleaned up lab area.

2. Phosphate, Nitrate and pH vs. Nutrient Level Curves

   i. Cleaned two beakers with soap and hot water. Rinsed with distilled water.
   ii. Performed pH, Nitrate and Phosphate tests on distilled water following Test-kit directions. Recorded the data in Excel™. Note: Rinsed Test tubes from kit before testing.
   iii. Repeated Step 2 for de-chlorinated tap water. Rinsed test tubes out first with regular tap water.
   iv. Prepared a 36.5 part per thousand salinity salt solution using Instant Ocean™. Recorded measurements in Excel™. Used refractometer to measure salinity. Repeated Step 2 for salt solution. Recorded results in Excel™.
   v. Calculated the amount of nutrient to add to salt solution based on the recommended dose (0.132 mL/L). Added 2 drops Part A& B to solution to make something close to a half dose solution. Repeated Step 2 for 50% solution.
   vi. Added 3 drops Part A&B to solution to make something close to a full dose solution. Repeated Step 2 for 100% solution.
   vii. Added 5 drops Part A&B to solution for a 200% solution. Repeated Step 2 for the 200% solution.
   viii. Cleaned up lab area.

Part C: Grow Algae on a harvestable scale and monitor conditions

1. Used the equipment and methods used and developed in **Parts A and B** to scale up production to cultures with volumes as large as their containers could hold. Started small and only doubled volume with each culture split, but tried to max out culture capacity (1.5 gallons to 60 gallons if not completing **Part Q** or 250 to 500 gallons if completing **Part Q**).
2. Constantly monitored salinity and added full doses of nutrient on a regular weekly basis. Set lights to 12 hr on/off cycles and used heaters and pumps to maintain air circulation and temperature. Used remaining tests in **Part B** if cultures started to die or look unhealthy.
3. Algae should grow once a stable environment with all the components essential to their survival was provided and should double in population every few days since they were single celled organisms. Mon-cultures were very sensitive and unstable, they needed constant attention for successful cultivation. Regular splitting of cultures was recommended for healthy cultures.

Part D: Calculation of Solar Drying Algae Harvesting Feasibility

1. Calculated the theoretical maximum evaporation rate of water per square meter ($L/s*m^2$) of a flat steel plate (assuming steady state, discounting energy stored in steel plate) using the data provided.
2. From this calculation determined if this was a feasible method for harvesting algae by calculating the area required to dry 1,000,000 gallons of culture.

Part E: Testing Feasibility of using a Centrifuge as an Algae Harvester

1. Obtained a centrifuge and the centrifuge tubes required to use it.
2. Tried centrifuging the algae (Nannochloropsis) on the maximum setting for several minutes to see if this separated the algae from the medium (should pelletize algae in bottom of tube). **Make sure that the centrifuge was balanced!**
3. If that worked, now try it on less intense settings. If that worked on less intense settings, considerer if this technology could work, potentially be scalable and was worth further testing and optimization.

Part F: Designing, Building and Testing Feasibility of Sonication Algae Harvester

1. Obtained sonicator (Sonifier Cell Disrupto 350, Branson Sonic Power Company) and set up to perform sonication.
2. Tried sonication of 1 L samples of algae (Nannochloropsis) and recorded observations (these samples were too big for tip on current sonicator to provide effect to rip cells apart).
3. Try sonication on smaller 15 mL samples of algae (Nannochloropsis) in centrifuge tubes to see if that would rip cells apart.

4. Based on these initial results, considered if this technology could work, potentially be scalable and was worth further testing and optimization.

Part G: Designing, Building and Testing Feasibility of Ultra-Violet Algae Harvester

1. Designed the UV harvester and constructed using the UV sanitizer, 1/2" and 3/4" tubing, connectors, clamps, water pump (Country Cottage CC210) and a 90^{o} PVC valve. Constructing a stand for the UV harvester would have be helpful in testing.
2. Researched the UV radiation exposure required to kill the algae and calculated the flow rate through the sanitizer to achieve the lethal exposure level.
3. Determined the flow rate of the UV sanitizer and recorded by pumping water from one container into a graduated cylinder while recording the time required to reach a certain volume with a stopwatch. Adjusted valve before sanitizer until kill flow rate was achieved (should be almost a trickle).
4. Once kill flow rate was achieved, noted how fast the flow was going. From there ran a sample of algae (Nannochloropsis) through the UV harvester and took several samples for observation to see if the algae died and sunk to the bottom over the next several days, which would mark success.
5. Based on these initial results, considered if this technology could work, potentially be scalable and was worth further testing and optimization.

Part H: Designing, Building and Testing Feasibility of Hydro-Cyclone Harvester

1. Since a hydro-cyclone is a scalable, but less powerful, form of a centrifuge, it might be a scalable way of separating the algae from their growth medium. To test this, conducted some internet research, then designed and built a rapid prototype with the help of the JMU Engineering Department. Provided them with some pictures, dimensions and hand drawings that were used to put proto-type into Solid-Works™ and "print out" a plastic 3-D prototype for testing.
2. Once the proto-type was in hand, fitted it with tubing at the in-flow and both outflows. Connected an aquarium pump to see if that initially would power the hydro-cyclone separation (Country Cottage CC210).
3. Measured and recorded the head pressure of the pump by connecting a 10 foot hose to the pump. While standing on the ladder, stretched the hose up, cut the pump on and with a tape measure, measured the head of the pump. Converted this into PSI.
4. To test the hydro-cyclone at a high pressure, constructed out of PVC a chamber capable of holding algae that was pressurized by a shop air system. This system had valves attached to it to allow this system to instantly build and release pressure. **Note: Made sure the components could handle the pressure first, including the prototype; running pressurized air through the prototype while standing a safe distance away behind a wall was sufficient in determining whether the prototype would withstand this application or not.**
5. Tried to note a visual difference in the two outflows, indicating separation, if not, taking cell counts of the outflows with a hemacytometer to determine the cell density may be able to detect a difference, but a visual separation of algae from their medium would have

been ideal in indicating a technology that could work, potentially be scalable and would have been worth further testing, quantification and optimization.

6. Based on these initial results considered if this technology could work, potentially be scalable and was worth further testing and optimization.

Part I: Designing, Building and Testing Feasibility of Electro-Flocculation Algae Harvester

1. Conducted a small scale electroflocculation experiment with a 9V battery, some stripped copper electrical wire for electrodes and a 25 mL sample vial filled with populated algae saltwater growth medium (Nannochloropsis). Placed the electrodes in the medium with space in between them to allow current to flow through the medium, connected to the battery and recorded observations and saw if technique worked as well as published reports claimed (should be able to see a visual difference, but if not cell counts on a hemacytometer could potentially determine a difference, but once again: A visual separation of algae from their medium would be ideal in indicating a technology that could work, potentially be scalable and would be worth further testing, quantification and optimization.)
2. Since Step 1 worked, scaled up testing using a larger container, aluminum welding rods for electrodes and a variable power supply as suggested in the published reports.
3. Measured and recorded the energy inputs of the reaction using an amp-meter, volt-meter and stop watch. Multiplication of all of those measured values rendered an energy input value.
4. Dried algae out for bomb calorimetry (See **Part L**) to determine a total energy output value for the powdered mass. Based on the initial results of the bomb calorimetry experiments, considered if this technology could work, potentially be scalable and was worth further testing and optimization.

Part J: Conventional Lipid Extraction

1. Start by measuring the salinity of the Nannochloropsis algae culture with the refractometer, repeat two more times to acquire a total of three samples. This data will be helpful in estimating the effect of the salt contained in the growth medium on the remaining measurements.
2. Weigh five separate glass beakers and record their masses. Take a total of three sample measurements for each. Using the plastic graduated cylinder; measure a volume of 1.000 Liters of algae culture out and place the liter in a pre-weighed beaker for drying. Repeat four times for a sample total of five beakers. Place the beakers under a fan for drying without grow lights.
3. When algae were dried, re-weigh beakers and record their masses.
4. Extract dried algal mass from each beaker separately, reweigh beakers after extraction and record their mass.
5. Perform conventional hexane extraction with blender while keeping each sample separate.
6. Weigh five of the clean glass Petri dishes and record their mass.

7. Collect five (size to be determined) milliliter samples from the hexane mixture. Place samples on the Petri dishes and re-weigh them. Record their mass. Allow these samples to dry (hexane should evaporate under atmospheric conditions), then re-weigh them again and record their dry mass.
8. Extract each sample from their respective Petri dish (re-weigh Petri-dishes afterward) and weigh them out for bomb calorimetry. Conduct the bomb calorimetry (See **Part N**) and record the data.
9. Analyze the results and determine the polar-lipid and energy yields per unit volume of algae culture using conventional methods. Compare the conventional data to the emulsification lipid harvesting data from **Part M**.
10. Based on the initial results, consider if this technology could work, potentially be scalable and was worth further testing and optimization.

Part K: Evaluating Isopropyl Oil Extraction Method to determine its scalability and feasibility

1. Began by trying solvent extraction on dried electroflocculated algae (top portion). Algae was encrusted on a whey plate, so added medical grade isopropanol (70%) to plate and swirled. Placed in sample vial. The salt present with the algae might have caused the isopropanol to "salt out" or separate into individual layers of water and alcohol. Noted that this occurred.
2. A published paper on the subject states that isopropanol can be added directly to wet algae mass for extraction of the oil. To test this, conducted an electroflocculation reaction (see **Part I**), scooped off some wet algal mass from the top and placed in an Erlenmeyer flask, added roughly the same amount (volumetrically) of isopropanol, placed a rubber stopper in top of flask, and shook vigorously. Noted observations (should turn emerald green).
3. Since any oils (polar lipids) that would dissolve into the alcohol should remain dissolved into the alcohol, ran the new solution through a coffee filter using a funnel and noted any observations.
4. Placed samples of the filtered solution and mass on top of the filter into sample vials to save for later study or observation. Tried to evaporate the filtered isopropanol by letting it dry in a whey boat to see what was dissolved in it. Recorded observations during the drying process and after.
5. Tried to convert the dried lipids to biodiesel (See **Part** O) and see if it burned. These remaining lipids could also have been tested using bomb calorimetry (See **Part N**), or the converted "bio-diesel" could have been tested using bomb calorimetry as well (See **Part P**). Note that the biodiesel reaction of transesterification was normally conducted on the polar triglyceride lipids, not non-polar lipids, so obtaining a bio-diesel reaction without the typically non-polar triglycerides would be interesting and definitely worth noting.

Part L: Determining the Energy Content of the Dried Algae Using the Bomb Calorimeter

1. Filled bomb calorimeter with 2000 mL of water.
2. Tore off a piece of brown paper towel, weighed and recorded the mass.

3. Cut 10 cm of fuse wire and attached it to the connectors in the bomb calorimeter, placed the paper towel inside the cup below the fuse wire, sealed the "bomb", and filled with 30 atmospheres of compressed oxygen.
4. Placed the "bomb" in the water bath, connected the leads, put on the lid and placed the temperature probe into the water bath. Attached probe to digital thermometer and started recording the water temperature at regular intervals. When the water was thoroughly mixed and the temperature readings level off, the "bomb" was ready for detonation.
5. Detonated the "bomb" and recorded the increase in temperature. Again waited for the temperature to level off. When the temperature leveled off, removed temperature probe, then lid, then "bomb" from water bath while not greatly affecting the volume of water in the bath and not disturbing the sample inside the "bomb". Released the pressure from the "bomb" gently, so as not to blow any remaining sample around, and opened the lid of the "bomb". Noted lack of a remaining sample mass along with other observations.
6. Prepared the bomb calorimeter for the next run. For algae weighed out approximately 1.00 gram samples and repeated Steps 2 through 6 until all samples were measured. Recorded observations and especially noted any anomalies.

Part M: Solvent Emulsification Lipid Extraction of Nannochloropsis Algae

1. Start by measuring the salinity of the Nannochloropsis algae culture with the refractometer, repeat two more times to acquire a total of three samples. This data will be helpful in estimating the effect of the salt contained in the growth medium on the remaining measurements.
2. Using the plastic graduated cylinder; measure a volume of 1.000 Liters of algae culture out and place into the algae inflow vessel. Using one of the glass graduated cylinders, measure a volume of precisely 1.000 Liter of hexane and place into one of the beakers as an inflow for hexane.
3. Prime the pump of the emulsification device and allow the entire device's system to reach steady state by re-circulating water from the five gallon bucket through the device. This will require water flowing through both the algae and hexane inflows as well as the device outflow. The recirculation valve of the device should be closed to prevent recirculation, allowing for a one-pass test of the device. The device should reach steady state at the maximum possible pressure drop to test for effectiveness of the device for algae lipid extraction. Set up the volt and amp meters on the pump to record the energy input of the pump.
4. Once the system reaches steady state, flip both inflow valves from the 5-gallon bucket of water inflow to the hexane and algae inflows. Start the stopwatch immediately at this time. Quickly switch the outflow valve from the five gallon bucket of water to the second graduated cylinder that serves as the product outflow. Switch back to water after the graduated cylinder reaches the desired volume. *Do not exceed capacity of the cylinder!* Shut off pump on the device after water was successfully re-circulating and change the water before conducting any more tests.

5. Wait for the emulsification to separate out into distinctive layers and record the volumes of these layers. Weigh five of the clean glass Petri dishes and record their mass.
6. Collect five 5 milliliter samples from the Hexane (top) Layer. Place samples on the Petri dishes and re-weigh them. Record their mass. Allow these sample to dry (hexane should evaporate under atmospheric conditions), then re-weigh them again and record their dry mass.
7. Repeat Steps 2 through 6 four times for a total of five samples.
8. Extract each sample from their respective Petri dish (re-weigh Petri-dishes afterward) and weigh them out for bomb calorimetry. Conduct the bomb calorimetry (See **Part N**) and record the data.
9. Analyze the results and determine the polar-lipid and energy yields per unit volume of algae culture using the emulsification device. Compare the emulsification data to the conventional lipid harvesting data from **Part J**.
10. Based on the initial results, consider if this technology could work, potentially be scalable and was worth further testing and optimization.

Part N: Determining the Energy Content of the Extracted Oil Using the Bomb Calorimeter

1. See **Part L** but place algae lipids instead of entire algae mass into bomb calorimeter

Part O: Converting the extracted algal oil into Biodiesel

1. Put on personal protection equipment (gloves and glasses) and determine the volume of oil to be converted by measuring the volume in a graduated cylinder.
2. Measure out 25% of that volume in methanol.
3. Weigh out on a scale the mass of Potassium Hydroxide (KOH) required to complete the reaction. Calculate the required amount of KOH by converting the ratio of 5 grams KOH per 1000 mL of oil to the volume measured in Step 1 (Note: Titration can help determine the specific catalyst ratio for each individual batch of oil). KOH absorbs water present in the air and water causes saponification of the biodiesel, so limit air exposure of KOH as much as possible.
4. Blend KOH with methanol by mixing. **Caution: This will get hot!**
5. Add methanol with dissolved KOH to the oil to be converted into bio-diesel. Make sure oil was in container that allows for mixing. Mix vigorously and let it set for several hours to overnight.
6. A complete reaction should separate out into two layers of methyl-esters (biodiesel) on top and glycerol on bottom. Record observations.

Part P: Determining the Energy Content of the Algal Biodiesel Using the Bomb-Calorimeter

1. See **Part L** but place algae biodiesel instead of entire algae mass into bomb calorimeter

Part Q: Growing enough algae to obtain a gallon of raw lipids for the Senior Symposium

1. Take the most hardy, reliable and productive algae strain (Nannochloropsis) and scale up to the maximum volume allowed by the cultivation tank or tubs using the techniques described in **Parts A, B and C**.
2. Add roughly half of the tank or tub volume to one of the 250 gallon pools for culturing. Scale up the culture to the maximum volume of the pool using the techniques described in **Parts A, B and C**.
3. Harvest the algae using the best harvesting method determined from **Parts D through P** and re-scale up the cultures until a gallon of lipids was obtained.

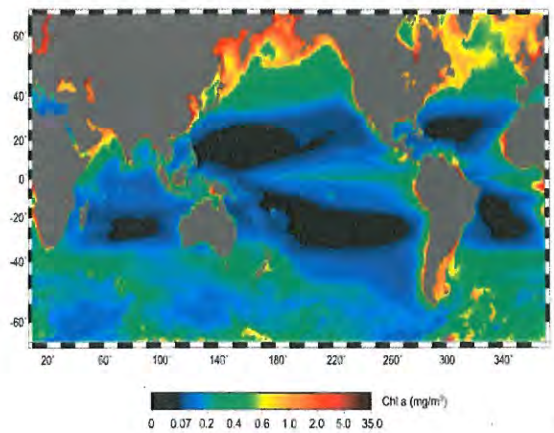
Results

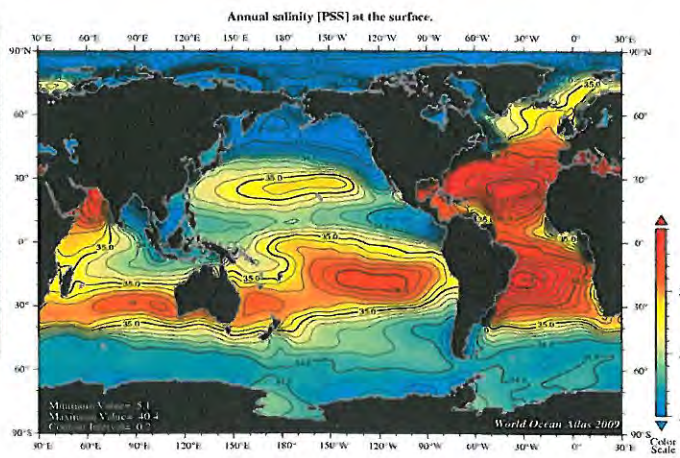
The results at this stage were still only preliminary and mostly qualitative in nature. Successful cultivation of algae was achieved using the equipment, techniques and curves in **Parts A to C**. The harvesting methods in **Parts D through H** were determined to be impractical from theoretical considerations and those with a reasonable theoretical backing were determined to be impractical by initial testing. Electro-flocculation (**Part I)** separates algae from their growth medium by forcing them to the top and bottom of the medium, allowing them to be scooped off and placed in a beaker for final drying. Unfortunately they did not combust in the bomb-calorimeter, the brown paper towel had a water bath temperature change of approximately 1.5 °C and completely vanished, the electroflocculated algae had no recordable temperature change and were still present after conducting the bomb calorimeter measurement outlined in **Part** L. Isopropyl oil extraction (**Part** K) worked by turning the isopropanol solvent emerald green and leaving behind an oily residue after filtration and drying, but did not yield lipids capable of being easily converted to biodiesel. Solvent emulsification of the growth medium with hexane separated into three distinct layers up to ratios of at least 20 parts suspended algae to one part hexane solvent. Further testing was required to evaluate **Parts J and M through Q.**




Discussion

The successful cultivation of the algae wass very exciting considering that none of the testing would have been possible without it. While the failure of the majority of the harvestings systems was discouraging, it sharpened the focus of the project. Solar Evaporation did not even make it off of the drawing board. Centrifugation worked, but was not really scalable to the quantities required. The same could be said of sonication. The flow rate of the UV harvester was too small to warrant further testing. The hydrocylcone was not really powerful enough to cause a noticeable separation. Electroflocculation seemed like it could really have worked, but the dried algae product would not combust. This could have be from the flame retardant properties of the reaction products ($AL(OH)_3$) or the reaction could have potential done something to the algae to oxidize them. Isopropyl extraction could be useful in extracting the polar lipids if they were of value, but the lipids of interest in this study were polar. More study and testing was required to collect the quantitative data necessary to effectively evaluate the harvesting systems proposed as well as the goals outlined in **Parts J and M through Q.** Algae have the potential to address some of the world's most pressing problems if fully developed and implemented, making research in this field critically important.





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Assessing the Practicality of Implementing a Nutrient Trading Program in the Shenandoah Valley

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Submitted to Dr. Jeffrey Tang

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Table of Contents

Introduction

Water quality issues have plagued the Chesapeake Bay for well over a century. Development, population growth, water and air pollution as well as other elements have overwhelmed the Bay's ability to support its complex ecosystem. Among the various damaging influences to the Bay's health, agricultural runoff remains one of the most detrimental concerns. Agriculturalists often over apply fertilizers on their farms that are rich in nutrients, which then wash into local waterways. Despite progress in pollution-reduction efforts, including the recently established Total Maximum Daily Loads (TMDLs), nutrient overflow into the watershed's creeks, streams and rivers is exceedingly difficult to target and confront. The main difficulties of this issue include identifying the true sources of these nutrients, determining what quantities came from each location, and creating an effective pollution reduction strategy. Establishing a nutrient trading program is one of the many proposed strategies being considered.

Many Shenandoah Valley farmers use poultry litter as fertilizer. Its high nutrient content makes for a suitable replacement of commercial fertilizers due to its relatively easy accessibility. It is regularly used in excess of crop nutrient capacities and without full consideration of the nutrient ratios required by the soil on which it is applied. In fact, the Environmental Protection Agency (EPA) Chesapeake Bay Program notes the Valley as being one of the three worst regions within the Bay watershed in terms of manure nitrogen use (cite graph from presentation?). In order to effectively diminish the frequency and impact of these damaging practices, stakeholders must be involved in the selected approach. If involvement and motivation are lacking, no matter how potentially efficient a program may be, it will be difficult to ensure successful execution of that solution as it relies on the actions of participants. Among the stakeholders, the participation of the Valley's farmers may prove most critical.

The problem addressed in my research is whether implementing a nutrient trading program involving farmers is a feasible strategy in the Shenandoah Valley. This required analyzing the history of Chesapeake Bay pollution management, the effect of agriculture in the region on water quality and the fundamental principles of nutrient trading programs. This is completed to the degree in which the background information regarding the pollution issue and the specifics of trading programs are comprehensible in a basic manner. Additionally, a substantial aspect of my research included the consideration of survey feedback from Valley farmers as well as other stakeholders. This crucial component will help to illuminate local perspectives essential to the success or failure of a trading program. Altogether, these analyses will have direct implications not only for the implementation of nutrient pollution management plans such as nutrient trading but also for the health of the Chesapeake Bay.

Using the feedback received from farmers and individuals knowledgeable with nutrient trading, some conclusions as to the feasibility of establishing a trading program in the Valley were made. There seemed to be notable willingness among farmers though more would have to be done to generate additional interest and convince participants that incorporating trading into their busy lifestyles would be worth it. This would likely include significant financial incentives and close stakeholder involvement to eliminate as much uncertainty regarding the details of participating as possible. Though the social obstacles must be considered when deciding whether or not to develop a nutrient trading program, the complexity of implementation may prove too time consuming.

The Chesapeake Bay and Eutrophication

The Chesapeake Bay is an estuary, meaning that it is a mix of freshwater from rivers and salt water from the ocean, and the largest one in the U.S. at that. It was formed almost "12,000 years ago when glaciers melted" and "holds more than 15 trillion gallons of water" (CBF_A, 2012). The Bay watershed, covering roughly 64,000 square miles across parts of six states and all of D.C., is "home to more than 17 million people and 3,600 species of plants and animals" (CBF_A, 2012). It has a "14:1 land-to-water ratio", the largest of any coastal water body in the world, and has "11,684 miles of shoreline...[more] than the entire West Coast of the United States" (CBF_A, 2012). These geographic characteristics highlight the extent to which activities on land impact the Bay. These activities include urban development corresponding to population growth and agriculture in particular.

One of the most pressing water quality concerns resulting from these and numerous other activities is nutrient over-enrichment. As excess nutrients, primarily nitrogen and phosphorus, reach the Bay they "fuel the growth of algae blooms" that, when they die, decompose "in a process that depletes the water of oxygen, which all aquatic animals need to survive" (CBP_A, 2012). This process is known as eutrophication. These algae blooms also "block sunlight that underwater grasses need to grow in order to continue providing food for waterfowl and shelter for blue crabs and juvenile fish" (CBF_B, 2012). Though the overall quality of the Bay has improved from 2008 to 2012, nitrogen pollution has gotten worse and phosphorus pollution has remained dangerous according to the Chesapeake Bay Foundation's 2010 State of the Bay report (CBF_C, 2010). This has led to failure in terms of improving the Bay's dissolved oxygen levels as seen in Figure 1.

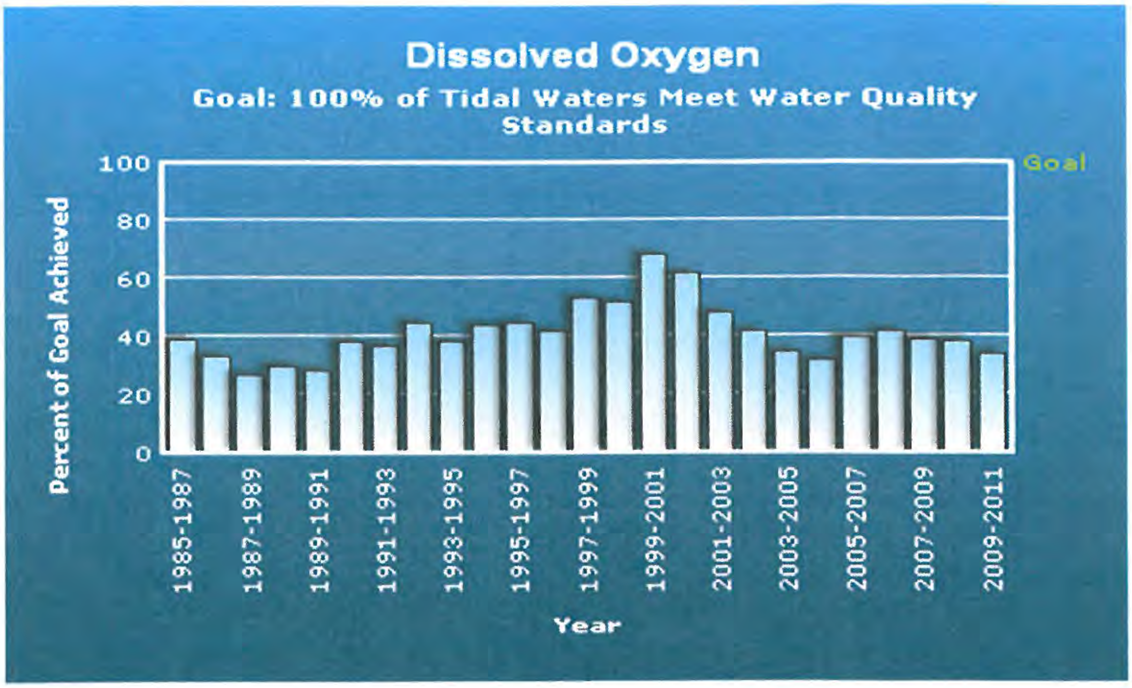

Figure 1: ChesapeakeStat provided data on percent of all tidal waters meeting dissolved oxygen standards. As indicated "34 percent of the combined volume of open-water, deep-water and deep channel water of the Bay and its tidal tributaries met dissolved oxygen standards" during the summer months from 2009 to 2011 (ChesapeakeStat).

Agriculture "covers 23% of the land area in the Chesapeake Bay watershed, making it one of the primary land uses in the region" (ChesapeakeStat). It is also Virginia's largest industry. Virginia's Department of Agriculture and Consumer Services ($VDACS_A$, 2012) estimates it has an "economic impact of $55 billion annually and provides more than 357,000 jobs in the Commonwealth" ($VDACS_A$, 2012). With more than 47,000 farms covering 8.1 million acres, approximately 32% of Virginia's total land area is dedicated agricultural territory ($VDACS_A$, 2012). Within the agriculture industry, this land area is used for a number of different practices including livestock operations and crop farming. Poultry is of particular importance in the state as it ranks fifth in turkey production and ninth in broiler chicken production in the nation (Virginia Farm Bureau).

Broilers, chickens raised for meat, are distinctly the most valuable and abundant commodity in Virginia. In 2010, broilers brought in roughly $623 million with cattle revenues a distant second at $373 million (VDACS$_B$, 2012). As previously mentioned, Virginia is a leading supplier of turkeys. In fact, Rockingham County "is the largest turkey producer in the nation and the largest dairy and chicken producer in Virginia" (CBF$_D$, 2004). Livestock in general, as of 2004, actually "outnumber the [Bay] watershed's human population by 11 to 1" (CBF$_D$, 2004). In order to match increasing public demand for meat and egg products, from chickens in particular, the concentration of livestock on farms has dramatically increased. On average across the nation, "the number of animals commonly raised on a single farm is...100 times greater on chicken farms than it was fifty years ago" (CBF$_D$, 2004). This consolidation of chicken and turkey production infrastructure has thus led to more damaging, concentrated environmental issues.

Supplying all this livestock means a substantial amount of manure is produced. That manure is regularly used by Shenandoah Valley farmers as an alternative to commercial fertilizers. It is cheaper, produced locally, and provides the nutrients needed for crop growth in the region. The economic practicality of such methods stems from the fact that there are over 180 million poultry animals in the Bay watershed (CBF$_D$, 2004). However, many of the physical and chemical characteristics of manure fertilizer make it naturally wasteful if used alone. Drawbacks include its relatively high mass and volume which make it difficult and expensive to transport. As a result it is spread in the immediate vicinity of where it is produced (CBF$_D$, 2004). Its "nutrient content varies more than that of manufactured fertilizer" and if farmers were to apply less manure to prevent phosphorus buildup they would then have to "also apply commercial fertilizer to meet the crop's nitrogen needs" (CBF$_D$, 2004). Another reason to target poultry manure in particular, other than its inherent inefficiencies, is that it is "higher in nutrients than cow manure, and the poultry industry has been expanding in the region, while milk and beef production have declined" (CBF_D, 2004).

Animal Manure Generated in Bay Watershed

Animal Type	Number of Animals	Pounds of Nitrogen	Pounds of Phosphorus
Beef	1,846,923	208,979,305	74,153,947
Dairy	697,595	161,380,163	25,103,581
Swine	1,254,026	38,448,422	14,647,018
Poultry	181,560,180	185,873,604	51,780,397
Total	185,358,723	594,681,494	165,684,943

Sources: EPA Chesapeake Bay Program, 2003

Figure 2: Animal counts and corresponding nutrient outputs (CBF_D, 2004).

Excess Manure Calculations

For Animal Production Regions in Chesapeake Watershed
Under Phosphorus Based nutrient management plans

Location	County Excess Manure Tons
Lower Susquehanna (NRCS)	286,196
Middle Delmarva (NRCS)	257,268
Shenandoah (NRCS)	600,070
Total Bay Watershed (ERS)	1,500,000

Figure 3: Regions with greatest excess manure use (CBF_D, 2004).

Unfortunately, due to improper manure application and a lack of preventative measures to deal with stormwater runoff, "as much as half of its nutrient pollution washes out of the soil and into rivers and streams or seeps into groundwater" (CBF_D, 2004). The United States Department of Agriculture (USDA) claims that animal operations in Rockingham produce "more excess manure than any other county in the nation" (CBF_D, 2004). Animal operation managers may have less than adequate storage facilities for this manure, thus, nutrients and other components often leach into the soil and into waterbodies. Nitrogen and phosphorus are both limiting nutrients for plants. Atmospheric nitrogen is broken down into usable forms, such as nitrate by decomposers, and is consumed by plant matter. The rate at which nitrogen is converted into an exploitable form, however, does not typically sustain the crops needs thus making it a growth inhibitor at times. Phosphorus, primarily found in soil via weathering rock in the form of phosphate salts, is limiting when the crops that take it up are exported, leaving the soil phosphorus-deficient. When manure is applied to crop soils, its uneven nitrogen-phosphorus (N:P) ratio usually results in the over-application of at least one of the nutrients. In the Valley, "manure application rates are based primarily on the management of N to minimize nitrate losses" (Moore, et al.). Poultry litter, manure mixed with bedding material, "has an average N:P ration of 3", hence a farmer is applying 3 atoms of nitrogen for every 1 atom of phosphorus on average when using it on his or her soil (Moore, et al.). Conventional wisdom was thought to be that "unneeded phosphorus would bind to the soil and stay put, but research has now established that once the soil reaches a saturation point, it begins releasing phosphorus into surface and ground water" (CBF_D, 2004). Thus, successive manure applications deposit more phosphorus than the crops can use as "'insurance' to maximize growth" (VNRLI, 2010). This method turns an important resource into a pollutant as phosphorus-saturated soil discards excess capacity, potentially at the rate of application. Such usage has contributed to Virginia being the source of over 27% of the nitrogen pollution and over 48% of the phosphorus pollution into the Bay (CBP_B). With an expanding poultry industry and growing population, nutrient runoff must be tackled in the Shenandoah Valley as well as across the watershed to ensure a healthy and vibrant Chesapeake Bay ecosystem.

History of Cleanup Efforts and TMDLs

Though the Bay remains largely impaired to this day, efforts have been made to improve its water quality. In 1983 the Chesapeake Bay Program is established and the first Chesapeake Bay Agreement is signed pledging the Executive Council partners (VA, MD, PA, DC, and EPA) to work on restoring the Bay. In 1987 the second Chesapeake Bay Agreement is signed and sets the first numeric goals to reduce pollution, the primary goal being to reduce N and P pollution by 40% by the year 2000. The Chesapeake 2000 agreement was then made when it became apparent that the 2000 deadline would not be met, pushing the deadline back to 2010. In May of 2009 President Obama signed Executive Order 13508 recognizing that insufficient improvement was being made and that government agencies would need to make policy changes to ensure future progress. Ultimately, in December of 2010 the EPA established the Chesapeake Bay Total Maximum Daily Load (TMDL) setting pollution limits on the amount of nutrients and sediment allowed into the Bay because the goal of the Clean Water Act (CWA) had yet to be met (CBF_E, 2012). Its goal is to "restore and maintain the chemical, physical, and biological integrity of the nation's waters" (EPA_A, 2013). The TMDL limits are meant to ensure that the CWA "fishable and swimmable" goals are met in the Bay by 2025.

Under the Clean Water Act states are required to assess their waterbodies to identify those not meeting quality standards. Those identified are listed as impaired and reported to the EPA. A waterbody could be listed for a variety of reasons such as high pathogen or low dissolved oxygen levels, among others. States are then required to "calculate the maximum amount of a pollutant allowed to enter an impaired water body…so that the water body will meet and continue to meet" water quality standards by conducting studies and drafting implementation plans spelling out how those input limits, or allocations, will be met (EPA_B, 2012). These pollution allocations and implementation plans serve as the basis for TMDL implementation or actual execution of agreed upon reduction strategies for impaired local waters.

The Chesapeake Bay TMDL incorporates all waters in the vast Bay watershed. However, in contrast to local TMDLs, "the Bay TMDL is based on protecting the Bay and its tidal waters [particularly] from excessive nitrogen, phosphorus, and sediment" (EPA_C). This larger TMDL sets a general 'pollution diet' for the Bay by combining "92 smaller TMDLs for individual Chesapeake Bay tidal segments" (EPA_C). The overall pollution limits for the Bay are "185.9 million pounds of nitrogen, 12.5 million pounds of phosphorus, and 6.45 billion pounds of sediment per year" representing a 25, 24, and 20 percent reduction in each, respectively (EPA_C). These watershed-wide allocations are then divided among jurisdictions and major river basins. Consequently, the responsibility of meeting these more specific allocations falls to the states.

In Virginia, the Department of Environmental Quality (DEQ) contracts out work for studies identifying pollution sources and appropriate reductions needed within impaired watersheds. DEQ's sister agency, the Department of Conservation and Recreation (DCR), then develops a watershed implementation plan (WIP) that spells out how the Bay TMDL limits will be met. The different state implementation plans submitted by December of 2010 formed the building blocks with which the EPA used to formulate the final Bay TMDL. DEQ's main method of tackling pollution is to target already permitted facilities such as wastewater treatment plants (WWTPs) holding Virginia Pollutant Discharge Elimination System (VPDES) permits. DEQ can enforce these permit limits more seriously as well as make them more strict if need be. Though a considerable level of flexibility is given to states in terms of how they wish to manage their pollution concerns, EPA holds the right to take action, such as expanding NPDES (national) permit coverage to include unregulated sources or revising TMDL allocations, if progress is insufficient.

At the beginning of 2012, each member state and D.C. submitted two-year milestones describing some of the activities planned to reduce the amount of pollution reaching the Bay. Virginia's undertakings concerning agriculture that are meant to be completed by 2014 are listed in Appendix B. All proposed actions can be viewed in Virginia's Phase I Watershed Implementation Plan.

Nutrient Trading as a Potential Solution

Among the approaches proposed to achieve the Bay TMDL goals is a market-based solution known as nutrient or water quality trading. It involves "the exchange of pollution allocations between sources...to achieve and maintain pollution reductions in a cost-effective and environmentally-beneficial manner" (CBF_F). The World Resources Institute working paper "How Nutrient Trading Could Help Restore the Chesapeake Bay" provides a clear description:

> In a nutrient trading market, sources that reduce their nutrient runoff or discharges below target levels can sell their surplus reductions or "credits" to other sources. This approach allows those that can reduce nutrients at low cost to sell credits to those facing higher-cost nutrient reduction options (Jones, Cy, et al., 2010).

The goal of a nutrient trading program is to reduce the costs of meeting water quality standards by shifting pollution reduction burdens to entities that can reduce their effluent quantities for a fraction of the price, say from an industrial facility to a farmer. Permitted polluters, such as WWTPs, factories, or sewage treatment facilities, release waste products into surface waters of the U.S. and are thus regulated by EPA. These permitted entities are known as point source polluters whose pollution can be linked back to their specific location or facility. These sources are typically the preferred target by federal and state agencies for pollution reduction efforts as progress can be easily calculated, often by straightforwardly measuring outputs at the point of discharge from a pipe. Thus, if stricter nutrient output reductions are mandated by federal and state agencies the focus will be on point sources to obtain the quickest results by making costly technical upgrades to their respective facilities. To reach permitted effluent levels, in this case for nutrients, point sources often resort to costly facility upgrades. Point sources "could save hundreds of millions of dollars per year if they purchase credits in lieu of implementing retrofits to meet at least a portion of their nitrogen reduction targets" (Jones, Cy, et al., 2010). Savings like this could apply for phosphorus reductions as well. In fact, "nutrient trading could yield nearly 60 percent cost savings for those WWTPs facing expensive upgrades" (Jones, Cy, et al., 2010). However, targeting permitted dischargers can only accomplish so much when the agriculture sector contributes a substantial share of nutrient pollution itself.

Non-permitted operations such as farms are known as nonpoint sources as any potential pollution generating and running off due to their operations is nearly impossible to link to their specific site. Nonetheless, to attain a reduction from the agriculture sector, nonpoint sources must play a role. By participating in a trading program, sources such as farmers could acquire a new revenue supply while simultaneously improving local water quality and that of the Bay. The involvement of these two parties would constitute a point-nonpoint trading system, illustrated in Figure 4. There are also point-point and nonpoint-nonpoint trading system types though the first does not address agricultural runoff and the second is currently impractical without mandatory nonpoint source pollution control requirements.

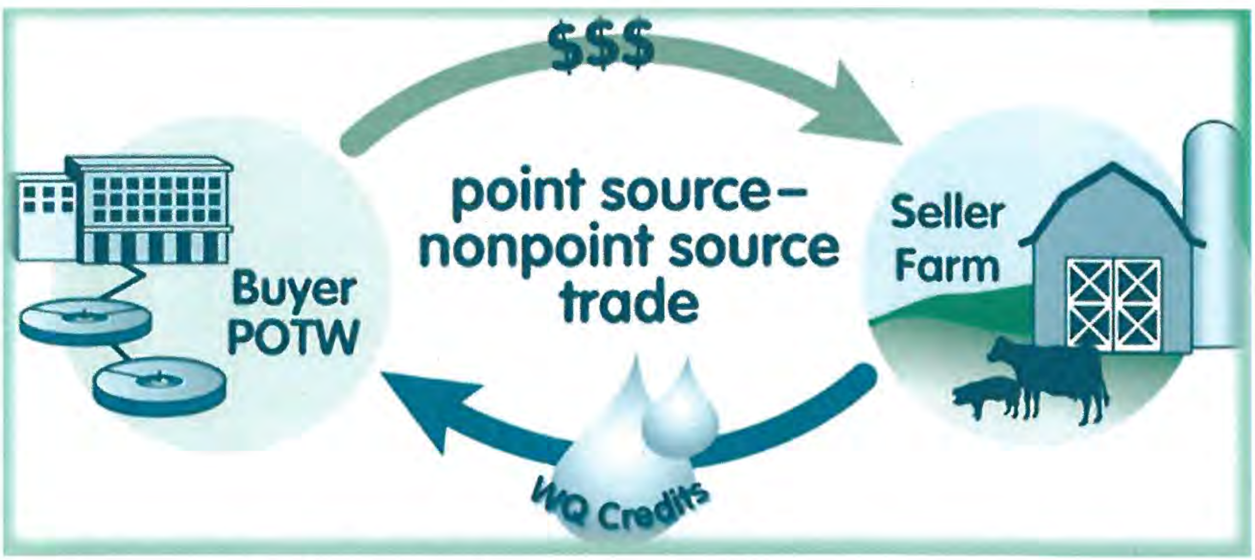

Figure 4: Point-nonpoint source trading scheme illustration.

In a point-nonpoint nutrient trading program, "a point source operator pays a nonpoint source – a farmer for instance – to implement a best management practice (BMP) that will reduce total nonpoint nitrogen and phosphorus discharge" (Stephenson, Kurt, et al., 1995). By paying a nonpoint source for a certain number of 'credits', a point source receives "additional pollution allowances that are based on the estimated reduction in nutrient loadings from BMP implementation" (Stephenson, Kurt, et al., 1995).

Though this may seem like a rather simple solution, there are a number of elements that must be taken into consideration when assessing the practicality of establishing a nutrient trading market that is capable of involving nonpoint sources. On the government side, quantifying nutrient discharge from nonpoint sources, frequent monitoring of control measures (BMPs), credible enforcement and determining clearly defined trading rules, among other actions, are required for any trading program to effectively function (Stephenson, Kurt, et al., 1995). In terms of quantifying discharge from farms, not only is each land area different in size but soil types and topography can even be different across the land area of an individual farm. Additionally, if the rules of a trading program are not clear and strictly enforced then ambiguity may drive away potential participants and misleading 'progress' will undermine the entire pollution reduction effort. Another major difficulty is accurately quantifying the inherent uncertainty of the control measure nutrient runoff reductions themselves. Trading ratios are often suggested as a means of taking this into account. For example, "Virginia requires an uncertainty ratio of 2:1…for all trades involving nonpoint sources" where "a regulated buyer must purchase 2 credits (or 'offsets') for every 1 pound of discharged [nutrient] it needs to offset" (Jones, Cy, et al., 2010). Additionally, from the nonpoint source side, trading circumstances must be enticing in order for voluntary participation to take place. If farmers are unable to generate enough credits or if the market for these credits is too small then there will be too little incentive. However, if a substantial enough market exists and realistic credit-generating activities are approved then farmers throughout the Chesapeake Bay watershed could benefit from nutrient trading.

Nutrient trading programs have existed in the U.S. since the early 1980s. The first program established "was a point-point trading system on a segment of Wisconsin's Fox River" (Stephenson, Kurt, et al., 1995). It applies to 35 miles of the river and has since spurred the initiation of "BOD [biological oxygen demand] trading programs on 500 miles of the Wisconsin River" (EPA_E, 2013). Unfortunately, "trading under these programs has been disappointing, involving a single trade on the Fox River between a municipal wastewater plant and a paper mill" (EPA_E, 2013). Reasons for limited participation in this case, such as restrictive or ill-defined regulations, continue to heavily influence the success of trading programs across the nation. In 1989, North Carolina launched the Tar-Pamlico program between point and nonpoint sources. The state realized that "the cost advantage of nonpoint sources in reducing nutrient loadings was the most important motivating factor for the creation of the nutrient trading program" (Stephenson, Kurt, et al., 1995). In this instance it was projected that meeting the objective "reduction though exclusive use of point source controls would cost between $50 and $100 million", however, "achieving the same reduction entirely through funding nonpoint source controls cost approximately $11.2 million" (Stephenson, Kurt, et al., 1995). Though trading program successes depend on a number of factors that must all work together, the Tar-Pamlico case shows that a well-designed program can substantially reduce pollution reduction costs while incorporating nonpoint sources. Other states with active trading programs include Oregon, Colorado, Minnesota, Ohio and Georgia among others (EPA_F, 2012).

In March of 2005, the Governor of Virginia signed legislation that allowed the creation of the Chesapeake Bay Watershed Nutrient Exchange Program. Point sources deemed 'significant dischargers', in addition to new and expanding facilities, are required to register for a Virginia Pollutant Discharge Elimination System (VPDES) permits. As a result, "the Exchange Program authorizes nutrient credit exchanges or payment into the Water Quality Improvement Fund (WQIF)" (EPA_G). The Exchange Program can facilitate trades, acting as a sort of trading broker, or trading partners can conduct transactions on their own accord. This program currently only allows for point-point trading of nitrogen and phosphorus but may authorize point-nonpoint source trades as it develops further (EPA_G).

Methodology and Findings

The factor I concentrated on for this project was the social aspect of implementing a trading program. To understand the points of view of farmers on nutrient trading programs I created a JMU IRB-approved survey. The survey, as seen in Appendix C, asks for information regarding familiarity with nutrient trading and opinions on such programs. Also included were a few general questions about the issues or challenges faced by the agriculture industry regarding water quality in the region, as they pertain to each individual farmer. Topics touched on were difficulties with implementing BMPs, their relative costs, poultry litter use as a fertilizer and litter pricing.

Getting in contact with farmers to obtain this feedback was incredibly difficult as the Virginia Poultry Federation, Virginia Farm Bureau and the Augusta and Rockingham County extension offices all could not provide me with personal contact information due to privacy concerns. Furthermore, going door-to-door asking water quality-related questions was off the table as I did not want to overstep my welcome, which for many farmers starts by simply encroaching on their property. The advice I received from a few professors was to set up shop at any location visited often by farmers and willing to support my effort. As a result, I set up a table at the Rockingham Cooperative, a stakeholder-owned retailer of farm products, to distribute an initial round of surveys face-to-face with farmers. Mr. Liggett, the retail division manager, kindly assisted me by teaching me how to indicate whether or not a potential customer was a farmer or not. As a stakeholder-owned retailer, most regular customers, typically farmers, have member identification numbers they inform the cashier of in order to get their share of the store's profits. The initial distribution I was willing to complete, over roughly 20 hours of attendance, brought in only 15 responses. Luckily, I was also able to contact Mr. Rountree from the National Association of Home Builders and Mr. Baxter from VDEQ who were both familiar with nutrient trading, in either a research or professional capacity, to see what they thought the general view of nutrient trading was among farmers.

From the limited survey feedback received I was surprised with the general reactions I observed. The first survey question was "Are you familiar with the concept of 'nutrient trading' or 'water quality' trading? If so, how would you briefly describe it?" Though not a single participant tried to describe nutrient trading in their own words, slightly over half of the respondents said they were either not at all or only vaguely familiar with the concept of nutrient trading. This is much higher than I expected, however, I believe that a few of the answers show a higher level of familiarity than what was truly representative because there was a description of nutrient trading at the end of the survey. The second survey question was "What is your opinion of nutrient trading? Do you think such a program would be beneficial to farmers if implemented in the Shenandoah Valley?" Most feedback indicated that the participants did think it would be beneficial however they offered some qualifiers like "if it's anything like carbon credits it won't work!" When asked if they "faced any major difficulties regarding water quality such as implementing best management practices", to see if the farmers were overwhelmed with farm management issues already, none of the participants noted any problems.

The next question asked how much it cost to install and maintain BMPs if they were implemented at all. The purpose of this was to get an idea as to what the economics of control measure application was. One farmer said that the main BMPs on his property cost roughly $112,000 to install and maintain where another said that the few he had were paid for with state grant money. What this showed was that government assistance is often needed because some of these BMPs can be very costly to install. Most of the farmers, when asked if they would be willing to implement BMPs to generate credits in a trading program, said they would be willing with some saying they would add more than they had already and others mentioning that they would need to know more about nutrient trading first. This was good to know because despite the impression from the first question that most knew of the concept, it indicated that educational promotion might sway those on the fence to participate in the future. Those who used poultry litter as a fertilizer on their farm paid about $10-15 on average per ton. One farmer noted that he would look for other fertilizers if the price went over $30 per ton. Though this was not looked into any further, this information would be key to figuring out the price of credits farmers would be working to accrue in a trading program.

The information provided by Mr. Rountree and Mr. Baxter, via email correspondence, was particularly helpful in order to gain perspective on the opinions of farmers on nutrient trading programs. One central idea expressed, of which I did not think of given my nonexistent experience with any farming community, was that trading is not farming. Farmers principally do not like to participate in non-farming matters, particularly those like nutrient trading that may have a steep learning curve and additional legal liabilities associated with them. Also, farmers do not want to give EPA or the states detailed information on how they farm. If a farmer was to participate in a nutrient trading program, he or she would be subject to increased monitoring and enforcement in regards to the rules of the trading program, and would likely have to release specific summaries of their farming practices. Despite these fundamental difficulties, Mr. Rountree noted that he thought in the long run, "farmers will recognize that trading is a good thing for them – that it will give them a new revenue stream for their farm, and that it is in their best interests to be seen as doing their part in restoring the Chesapeake Bay" (Rountree).

Conclusions

From analysis of the survey feedback and considering the information provided by Mr. Rountree and Mr. Baxter, a few preliminary deductions can be made. The primary, overall conclusion is that there is most likely enough potential interest to establish a nutrient trading program in the Shenandoah Valley between point and nonpoint sources. There are, however, a few concerns. There would have to be significant financial incentives offered in order for farmers to think twice about diving into the steep learning curve and additional legal liabilities. There would also have to be an educational push to generate additional interest and dismiss doubts regarding trading programs. For example, a farmer would have to be certain that his efforts in the program would lead to the generation of sellable credits down the road or the initial investment may not be worth the risk. There would have to be close stakeholder involvement, particularly with farmers, to ensure that interest is maintained and to dismiss any feelings that a trading program would take advantage of their participation. With all of this said, however, it may simply take too long to establish a nutrient trading program on a scale large enough to meet the Bay TMDL limits by the year 2025.

There were many project limitations that had to be taken into account when making these conclusions. I did not dig very deep into the economics of nutrient trading programs such as the price of credits, the potential savings versus targeting point sources alone and the potential average income of participating farmers in the region. Additionally, it was very difficult to get in contact with farmers to get their feedback. If a few more months of survey distribution were to occur then surely a more detailed and well-rounded set of findings would have become clear. Nonetheless, the implications of this type of research could help keep market-based solutions for restoring the Chesapeake Bay on the table for policymakers in the future.

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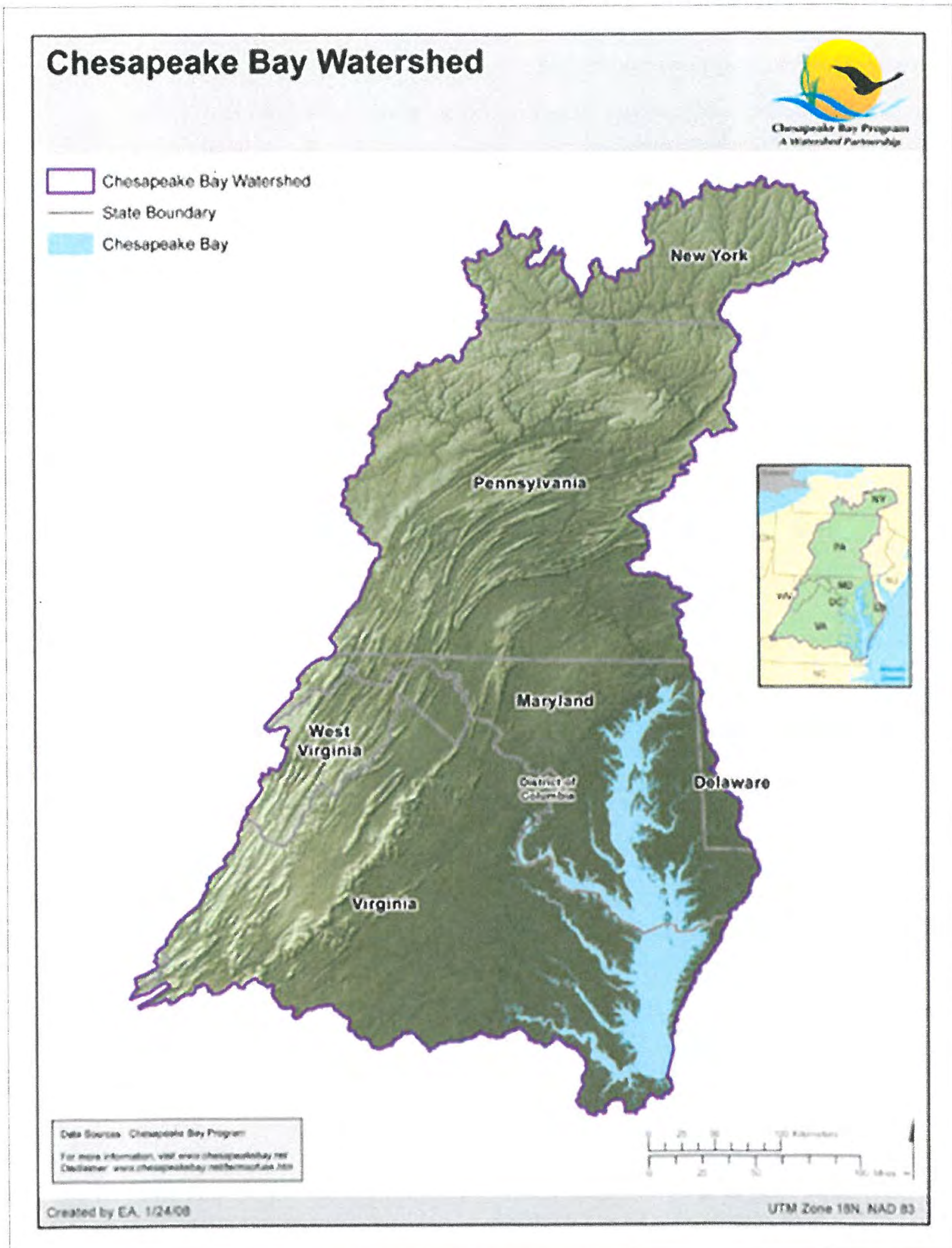
Appendix A: The Bay Watershed



Appendix B: 2012-2013 pollution reduction milestones for agriculture in Virginia (EPA_D)

January 1, 2012 – December 31, 2013 Programmatic Two-Year Milestones

Target Date	Milestone (WIP page reference)*	Deliverable	Lead Agency	Comments/Status Updates
Agriculture-				
12/31/2012	Improve the state's capacity to respond to water quality complaints/inquiries and provide outreach and education to producers concerning environmental stewardship. (Phase 1 WIP, pg. 55)	Establish two new Agricultural Stewardship Act Coordinators	VDACS	Two new coordinator positions were created
12/31/2013	Renew relationship with fertilizer companies to encourage and track precision agricultural application (Phase 1 WIP, pg. 65)	12,500 acres of precision agriculture annually	DCR	
12/31/2013	Increase nutrient management planning to 70% to include all applicable state-owned land (Phase 1 WIP, pg. 61)	669,722 acres NM annually	DCR	DCR anticipates obligations of $36.2 million in 2012 and $24 million in 2013 for the 47 SWCD's. This funding includes $4 million for livestock exclusion, $3 million per year for the implementation of local TMDLs, and $2 million for animal waste practices. The remainder will go to the general fund for agricultural BMP implementation. Technical assistance to SWCDs is also included.
12/31/2013	Renew enhanced funding for livestock exclusion (Phase 1 WIP, pg. 63)		DCR	
12/31/2012	Report voluntarily installed conservation practices for 6 pilot SWCD's (Phase 1 WIP, pg. 54)		DCR	
12/31/2013	Implement voluntary Best Management Practice collection statewide (Phase 1 WIP, pg. 54)		DCR	
12/31/2013	Initiate Resource Management Plan framework (Phase 1 WIP, pg. 59)	Agricultural Certainty Program	DCR	

Appendix C: IRB-Approved Survey

Nutrient Trading Survey

I am a senior at James Madison University. I am currently working on a senior capstone project regarding nutrient trading in the Shenandoah Valley. This involves gathering information about familiarity with nutrient trading and opinions on such programs. A sample definition of nutrient trading is provided at the end of the survey. Also, I would like to ask a few general questions about the issues/challenges agriculture faces regarding water quality in the region. Your answers are essential to the viability and usability of my work. Your answers will not be individually identifiable and will only be used in my senior project for obtaining a general view on nutrient trading. **If you are not a farmer, do not represent farmers, or do not manage a livestock operation this survey does not apply to you.** This survey should take about 10-15 minutes to complete. If you are unable to answer a question, simply leave it blank.

1. Are you familiar with the concept of "nutrient trading" or "water quality trading"? If so, how would you briefly describe it? (If not, a short summary from the World Resources Institute is provided at the bottom of this survey.)

   Not at all familiar   Vaguely familiar   Somewhat familiar   Very familiar

2. What is your opinion of nutrient trading? Do you think such a program would be beneficial to farmers if implemented in the Shenandoah Valley? (If you are not sure, simply state any uncertainties as well as other thoughts about participating in such a program.)

   Would it be beneficial?   Yes   No

3. In the past few years, have you faced any major difficulties regarding water quality such as implementing best management practices (BMPs)?

Biodiesel Research and Development

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September 30, 2011

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Executive summary

More than 90% of the World's transportation relies on fuels derived from oil, and the global reserves are being rapidly depleted. It is undeniable that oil will one day run out, and the loss of that resource will have a profound impact on the production and distribution of all goods, including food, and will dramatically alter the global economy. The United States is particularly vulnerable to the depletion of reserves due to its high rate of oil consumption and it's the large portion of oil that is imported from around the world. In order to move away from this oil dependency, the fuel economy of vehicles must be improved and the development of clean, renewable fuels is key to move past oil dependency and create a cleaner environment for future generations.

Our project focuses on the incorporation of biodiesel as a key fuel source for the U.S and the ability for farmers to complete it on a small to medium scale. Currently biodiesel processors on the small scale are not cost effective and do not ensure the product produced will meet with ASTM standards for commercially viable biodiesel. Our goal is to discover a solid-state catalyst that will enable a more cost effective and reliable process for small to mid sized biodiesel processors. Currently much of the canola that is grown in the Shenandoah Valley is shipped across the state to be pressed and have the oil extracted then the dry grains returned as feed. If there was a viable mid-scale biodiesel processor that could produce quality fuel reliably, there could be a market in the area for farmers to start to press and use the oil themselves. This would give another opportunity for farmers to make money on another aspect of their harvest as well as providing the valley with an opportunity to use more renewable fuels.

Summary of the Problem

One of the problems with current biodiesel production is the cost of catalyst used in every batch of biodiesel made. The current process of transesterification involves the addition of methanol, a catalyst (normally KOH or NaOH), and the feedstock oil of choice. There is no current process that allows for catalyst recovery from the solution since the catalyst is dissolved. This raises the price of each batch of biodiesel that is made and is an inhibitor for biodiesel becoming cost effective in the market. Another problem with current process is the pH balance with the catalyst and the feedstock. Some feedstocks, particularly used cooking oil, have a high acidic content that can neutralize the basic catalyst and cause the process to not run to completion. The main problem from the incomplete process is the free and total glycerin levels that are still in the biodiesel and cause problems in engines such as clogs and reduced efficiency.

Introduction to Potential Solutions

A possible solution to the catalyst problem with current biodiesel production is the use of a solid-state catalyst. A solid-state catalyst has the possibility to solve many of the problems currently being faced with using NaOH. We believe that a catalyst that will not dissolve into solution would therefore not be pH affected and be able to handle higher acid levels in the feedstock. This will allow for reduced amounts of catalyst to be used, which will save money and allow for a wider range of feedstocks to be feasible for converting to biodiesel. Another advantage to finding a solid-state catalyst is the possibility of anchoring the catalyst to a metal surface, such as a static mixer, in order to increase mixing efficiency and ensure completion of the transesterification process. The catalyst would have the possibility of being able to catalyze multiple batches of biodiesel saving time and money from adding measured amounts of catalyst to each batch.

An advantage of biodiesel in the current market is the similarities of biodiesel to regular diesel in storage and transportation (Biodiesel Storage, 2011). The most important factor for the storage of biodiesel is to protect it from contamination, similarly to petro diesel. It can be stored in the same aluminum tanks and transported via rail or trucks allowing for it to use the existing infrastructure. The only change that would need to be made to convert to biodiesel at the pumps would be to add a filter to ensure any large particles are removed before it goes into a vehicles gas tank. The filters would also help to move any excess free and total glycerin that may have not been fully removed during the original processing of the fuel.

Scope of the Proposed Research Study

The desire to find a solid-state catalyst will in theory solve many of these problems. We believe that a catalyst that will not dissolve into solution would therefore not be pH affected and be able to handle higher acid levels in the feedstock. This will allow for reduced amounts of catalyst to be used, which will save money and allow for a wider range of feedstocks to be feasible for converting to biodiesel. Another advantage to finding a solid-state catalyst is the possibility of anchoring the catalyst to a metal surface, such as a static mixer, in order to increase mixing efficiency and ensure completion of the transesterification process. The catalyst would have the possibility of being able to catalyze multiple batches of biodiesel saving time and money from adding measured amounts of catalyst to each batch.

The research that we our proposing would look to prove the possibilities laid out in the prior paragraph. Through academic research we discovered that many elements in the hydroxide, and oxide groups have the needed characteristics to be a possible solid-state catalyst in the transesterification process. Our research plan is to run small-scale samples of the catalysts that we can procure through our resources at JMU, and compare them to the known standard of NaOH. Once we discover which have the best results in the small-scale test we will run the sample of biodiesel on a gas chromatograph in order to complete the ASTM D6751-11 for free and total glycerin. This test will show us conclusively whether or not our catalyst can complete the transesterification process and create biodiesel that matches the set standard. Once we have the results from that test we will recover the catalyst from the prior samples and use it again to ensure that it does not lose it's catalytic properties after just one run of biodiesel. The samples will again be tested on the GC to the ASTM standard to ensure that it is still quality biodiesel.

If time allows after completing the rest of the tests, the next direction we want to take our project is finding a way to embed the catalyst onto a metal surface. The recovery of free floating catalyst on a large scale, even though it separates from the other components, would be a difficult and most likely expensive process. We plan on testing different methods, such as sand blasting, heating the metal to a point where the catalyst combines with it, and other methods after more research. These tests will allow us to run more samples to see if the catalyzed metal will have enough interaction with the feedstock and methanol to run the process to completion. We again will run the ASTM tests on the GC to validate the quality of the biodiesel created to ensure it would be good enough to sell.

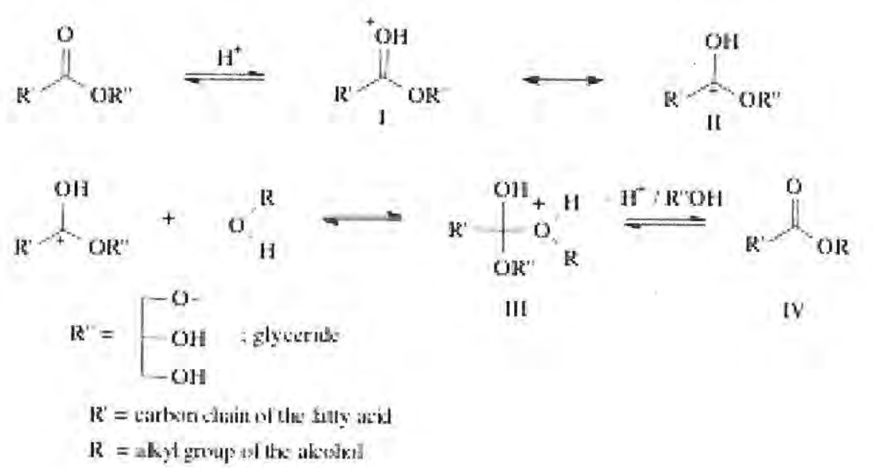
Biodiesel Fuel Testing

This summer we began research regarding the formation of biodiesel produced by the transesterification reaction of an alcohol and triglyceride. The triglyceride reactant used can be any oil, such as canola, soy or waste oil, but the initial oil used will affect the properties of the biodiesel produced. Triglycerides, which have longer carbon chains and are saturated with hydrogen, will produce biodiesel with a higher melting point compared to short and unsaturated fatty acids. This can affect fuel quality. The alcohol we chose to focus on was Methanol, due to its exceptional reactivity in the transesterification reaction as well as its commercial availability and feasibility. Ethanol was also tested but did not perform as well in completing the desired reactions. This is likely due to its increased steric hindrance.

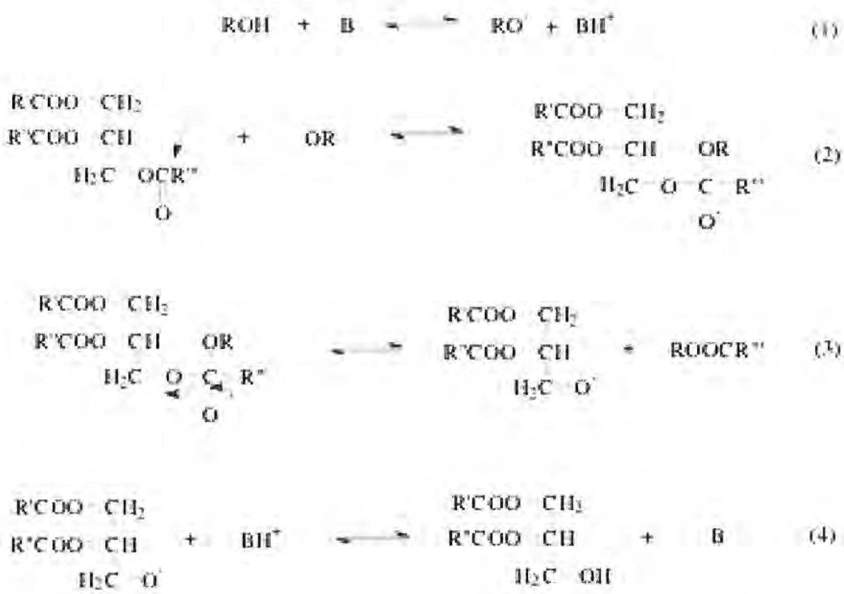
For the transesterification reaction to occur, it is almost always necessary to add a catalyst. The catalyst may be an acid or base, and is normally homogenous, being soluble in the alcohol phase.

Understanding the Transesterification Mechanisms

Acid Catalyzed mechanism



Base Catalyzed Mechanism



Schuchardt, U.; Sercheli. R.; Vargas, R. M. Transesterification of Vegetable Oils: a Review. *J. Braz. Chem. Soc.*, Vol. 9, 199-210, 1998

The base catalyzed method is generally preferred to the acid catalyzed one as it catalyzes the reaction faster. One of the disadvantages of these methods is that the resulting biodiesel must be titrated to return it to a neutral pH after the reaction is complete. This is one of the more costly aspects of reaction because both the catalyst is lost and the corresponding titrant must be replenished. A method of avoiding this however would be to use a heterogeneous catalysts.

Proposing the Need for a Solid State Catalyst Imbedded In or Coating a Static Mixer

A heterogeneous catalyst is a catalyst which exists out of phase with the reaction. This poses certain challenges as the reaction itself is already two phases, an organic phase containing the oil, another alcohol phase. Normally the catalyst is dissolved in the alcohol phase. Using a solid phase [heterogeneous] catalyst would result in easy separation of the catalyst and product, but new challenges must be overcome if the reaction is to be successful. The solid catalyst must be in contact with both the alcohol and the oil simultaneously or it will not be able to function as a catalyst. This condition is difficult to achieve and to do so I suggested the creation of a solid state catalyst imbedded onto a static mixer. The catalyst would possess either the acidic or basic characteristics already described but it would have minimal solubility in the reaction mixture, with the vast majority of the catalyst remaining in its own distinct solid phase. The acidic and basic nature required would generally limit the catalyst choice to polar covalent and ionic compounds.

Additional Catalyst Characteristics and Analysis

The catalyst must also have a low solubility in both the oil and alcohol phases as well as in the resulting biodiesel and glycerol products. The solubility of ionic and polar covalent compounds in a nonpolar solution is normally quite low. Methanol, being much more polar then triglycerides and biodiesel, will likely be the cause our primary solubility concerns. There may be exceptions to this, especially due to the possibility of the catalyst dissolving in the polar glycerol. We must therefore exhibit care to note the loss of catalyst over the coarse of the reaction. If we do not the catalytic mixer would soon become useless do to the catalyst being stripped from the static mixer. The solubility mentioned above also presents another challenge because most solubility constants are for water and not for methanol and therefore the individual testing of the different proposed solid catalysts is required to ensure the selection of one that will remain in its own phase.

Seeking The Correct Catalyst

Finding which catalyst to test began our next phase of research. Oxides, specifically ones were oxygen is bound to an electropositive element, tend to act as a base in water. Metal hydroxides also exhibit basic characteristics in water. Due to the polarity and hydrogen bonding of methanol [our selected alcohol], we expected these compounds to exhibit similar basic character, but not identical total behavior, as when mixed with water. As the literature supported our hypothesis we chose to focus on these two types of compounds. We crudely then tested the solubility several catalysts to see if any could be immediately eliminated by observable solubility. None of the tested oxides or metal hydroxides showed observable solubility. Surprisingly, however, despite the large limitation of significant three phase contact we observed that Barium Hydroxide did seem to catalyze the transesterification reaction and did so without the addition of external heat [which would under most circumstances be required]. Thus far all of our transition metal oxides have shown themselves to be relatively insoluble.

That the compound barium hydroxide had shown very promising results in successfully completing the transesterification reaction without the addition of external heat has caused our research to take additional turn. We are currently researching Barium Hydroxide's solubility to ensure that it's apparent catalytic success was not caused by its having too large of an ionic dissociation in methanol thus causing it to act as a homogeneous catalyst instead of a heterogeneous one. If this were the case, and even if not so, I would suggest investigating other hydroxides of alkaline earth metals, ones with a smaller radius, as this should show a lower solubility and could therefore be considered as a suitable replacement.

Biodiesel Fuel Testing

Bio Fuel must meet strict ASTM [American Society for Testing and Materials] standards to be used commercially. To test the quality of our biodiesel products we must measure the free and total glycerol in the solution with the biodiesel. Although biodiesel has many standards it must meet, an ASTM measurement of free and total glycerol is the most important and difficult test to pass and can be used as an overall judge of quality. This is because glycerol is always a product of the transesterification reaction. It also is very polar, forming a gel like precipitate in large quantities. If ignored and not properly separated it can easily clog engines and therefore we must test the total glycerol in solution. The testing can occur only after we separate the biodiesel from settled glycerol to ensure an accurate measurement of the biodiesel solution concentration. The ASTM provides strict guidelines for how to measure the free and total glycerol and the amount of which can be present in commercial grade biodiesel.

Gas Chromatography and Testing Methodology

To test the free and total glycerol content of biodiesel to ASTM standards we use a gas chromatogram [GC] with a flame ionization detector attachment (FID). The Department of Chemistry graciously has lent us a refigured Agilent 5890 GC. In a GC a liquid sample is injected into a long column that is housed within a variable temperature oven. Various columns are filled with different packed materials. For the testing of biodiesel we use a polar, heat resistant column. This necessary column was purchased specifically for our experiment with the funding from the 25X25 grant.

Hydrocarbon compounds within the sample being tested move through the GC column at a rate determined by the equilibrium between their vapor phases and their attraction to the packing material within the column. The stronger the molecular attraction between the compound and the column, the longer the retention time of the compound will be prior to it being eluded out of the other side of the column. Our column is packed with a polar compound. As injected polar compounds have stronger interactions with a polar column, the more polar a compound is the longer it will take to elude. Additionally as longer hydrocarbons have a lower vapor pressure than shorter ones do, they will spend less time in their vapor phase and therefore have longer retention times than the shorter hydrocarbons will. As the GC runs, the temperature is gradually raised to ensure that the less volatile compounds will have an appreciable equilibrium in the vapor phase and will eventually elude. After elution, the FID detector burns the hydrocarbons thus eluded to detect and measure the amount of carbon in each elution. With this measurement we can determine the relative amounts of a substance by carbon mass. By then using a set of standard solutions containing glycerol, we can determine the retention times for the glycerol in our biodiesel sample. Combining this information with the percent of carbon by mass that is a glycerol as determined by the FID enables us to determine the free and total glycerol content in the original biodiesel sample.

Biodiesel Considerations- Large Scale vs. Small Scale

There are many factors that must be considered when selecting a site for a new biodiesel facility. Of utmost importance is the availability of feedstock (raw, processed, or used oil). Transportation costs dictate how far an oil or oilseed crop can be shipped before it becomes too costly or too energy intensive to deliver. The further the raw materials have to be shipped results in more costs for the biodiesel facility. Once they reach a certain shipping cost, the process is no longer economically viable for them. Most of the prime sites have already been developed, with each facility consuming all of the available feedstock within a certain radius. This creates "fringe regions" which exist between the viable circles of adjacent facilities, where the cost to ship crop from these locations is at or above the cutoff value for economical production of fuel. For example see Figure 1.

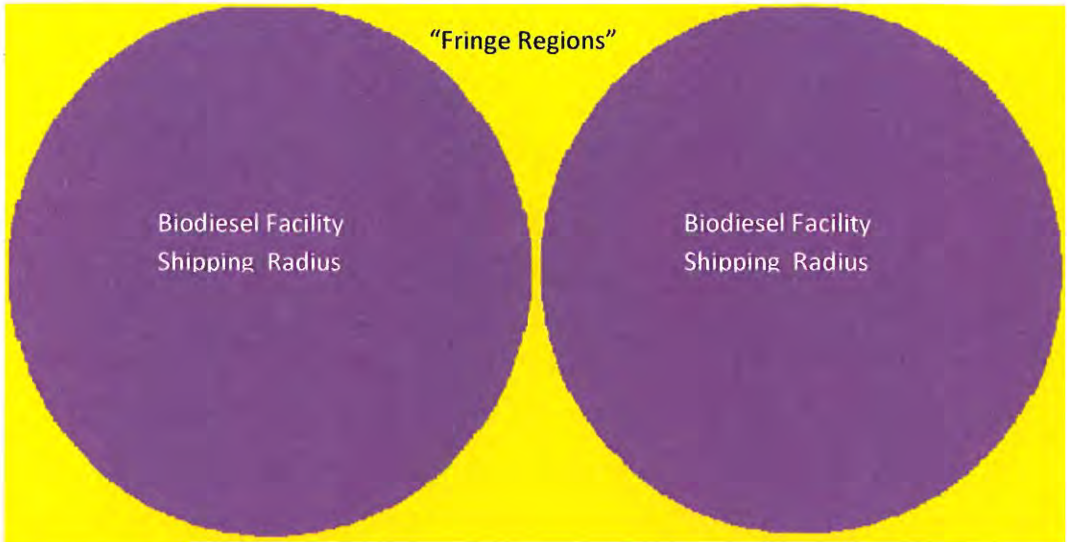


Figure 1: shows an example of the "fringe regions" created by the large scale biodiesel facility shipping radius.

The large scale biodiesel facilities will use the oil or oilseed crops from their radius; however, the fringe regions are perfect for small scale biodiesel processors. Since small scale processors are relatively inexpensive, there can be multiple units situated throughout the fringe regions. By definition, the small scale processors will not be producing as much as the large scale producers; however, the small scale processing units are ensuring that the fringe regions are not being wasted. The following figures will show the number of biodiesel production facilities in the US and more specifically in Virginia.

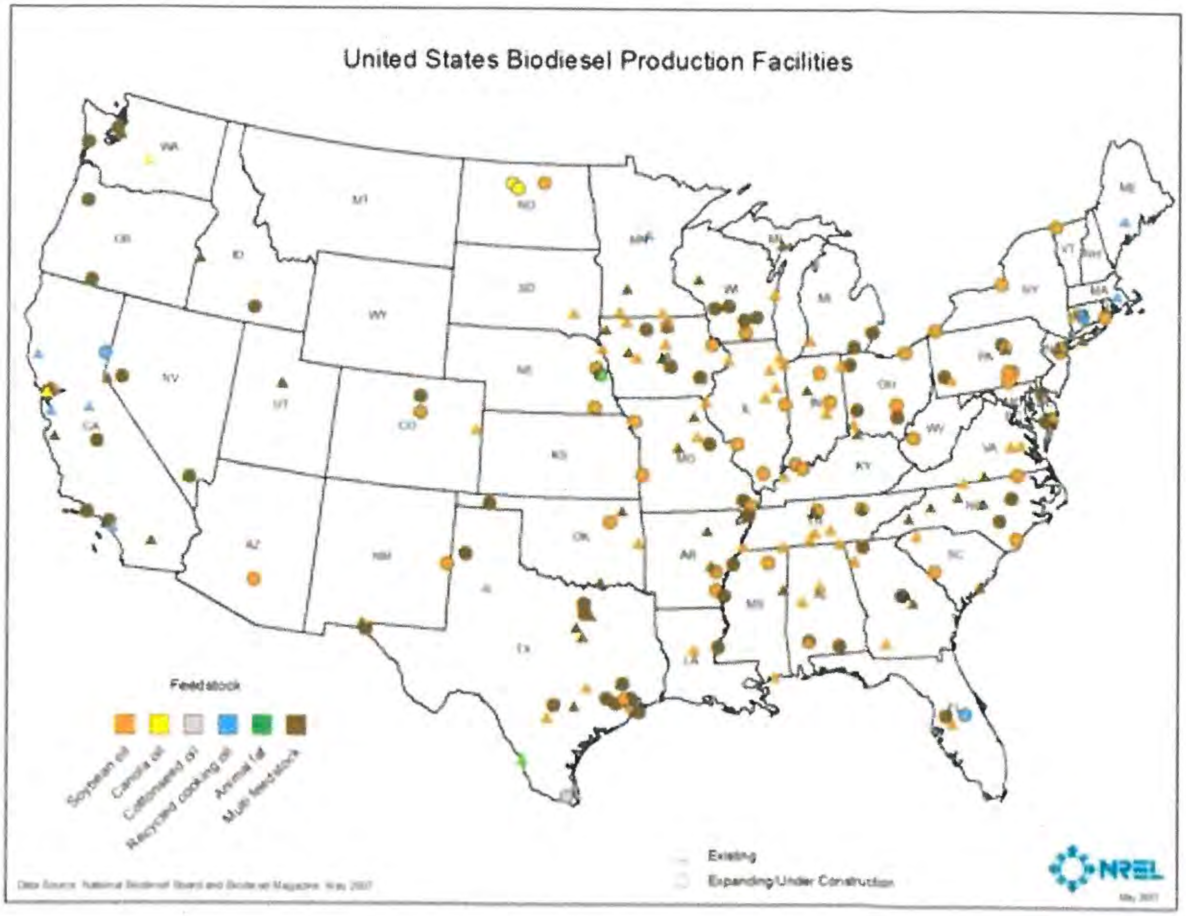


Figure 2: shows an image from NREL of the Biodiesel Production Facilities in the United States as of 2007. http://www.heatingoil.com/articles/heating-biofuel/

As seen in Figure 2, there are a significant number of biodiesel processing facilities in the US; however, there is ample room for additional facilities. A majority of the large facilities are not in Virginia, and Figure 3 reinforces this statement.

Figure 3: shows the biodiesel production facilities located in Virginia in 2011. The facilities are highlighted with a purple dot. This information is from the National Biodiesel Board using their Location Finder tool. http://www.biodiesel.org/buyingbiodiesel/plants/biomaps/biomaps.shtm#app=d088&4810-selectedIndex=0&fd8d-selectedIndex=1&65ce-selectedIndex=0

According to the National Biodiesel Board, in 2011 there are five (5) biodiesel facilities in Virginia (Biodiesel.org, 2011). They all appear to be on the outside boarders of the state, leaving central Virginia and the Shenandoah Valley with a sizable absence of facilities. According the the National Renewable Energy Laboratory's (NREL) TransAtlas tool, the biodiesel facility shown near Winchester is no longer operational ("Home".maps.nrel.gov, 2011). Certain regions that do not have a large scale biodiesel facility within close proximity could benefit from small scale biodiesel production. By using small scale biodiesel production, the regions would be able to adapt the process for which feedstock, or feedstocks, they will be using. These regions could benefit from the use of used cooking oil as a feedstock. Since larger scale operations are generally tailored to a specific feedstock, the small scale production in the respective regions will have an economical and competitive advantage by being able to diversify their feedstocks. These feedstocks will all come from that region, so it will alleviate the need to ship their oil or oilseed crops to a distant location. The localized fuel production means that all of the economic gain associated with the fuel production will be retained in those regions.

Review of Existing Biodiesel Processor Options

The majority of the small scale biodiesel reactors on the market are generally a terrible value with respect the fuel they produce. The large scale biodiesel processors are made from higher quality materials and tend to actually produce ASTM quality fuel. For the purpose of the Shenandoah Valley and the scope of this project, we will only be focusing on the small scale processors.

For small scale biodiesel producers the processors range anywhere from about $2,000-$95,000 with varying quality of materials. At this price range the research did not come up with any units that were continuous flow systems, they are all batch systems. Examples researched include: BioPro 150, BioPro 190, BioDiesel Processor (Organic Mechanic), B-500 Stand Alone Batch Biodiesel Processor, NWR Alternative Fuels Biodiesel Processor, BioPro 380, Turner Biodiesel 70 and 180 Gallon, B-150, Flournoy Green Tech Processor, FuelMeister II, and the Freedom Fueler. A majority of the systems consist of two large, plastic containers with conical bottoms, a wire/thin metal frame, some plumbing, and a pump; these systems tend to run between $2,000 and $6,000 (with the exception of the B-500 which is being sold for $10,000). The experience that JMU has had with the processor of similar characteristics (our Fuel Meister processor) has been that it will make the biodiesel, but the quality of the fuel is significantly poor. The method of doing all of the mixing by pump is an inefficient method and with the oil and methoxide not mixing well, poor fuel is produced.

The processors ranging from $6,000 and up actually appeared to be of quality construction with welded stainless steel tanks and metal plumbing (again, with the exception of the B-500). The metal construction of these processors is a great advantage over the plastic construction of the cheaper versions because biodiesel tends to degrade plastic parts. We learned from the JMU Biotrike that the biodiesel ate away at the plastic and rubber seals, causing it to leak. About half of the models at this price range also had some sort of methanol recovery device incorporated into the system. The more expensive models tend to produce more, as one would expect with such an increase in price.

Despite differences in quality of construction, price, and output the processors out there on the market a generally similar. They all do batch processing, although there was one model that was a commercial scale processor which cost in a range of \$1,550,000-\$1,880,000 and was advertised as a continuous flow processor (the Denami 600 Processor). Each model uses methanol and potassium hydroxide, in a couple cases they used sodium hydroxide. The quality of the fuel from each individual processor is unknown, probably because no one has actually tested the fuel that has come out of these small scale processors. In our opinion, the Turner Biodiesel processors (\$6,495-\$11,500) and the Flournoy Green Tech processor (\$95,000) have the best chance of producing a quality fuel. The Freedom Fueler (\$3,320) claims that their processor makes ASTM quality biodiesel; however, they have not presented data to support those claims. This processor is also one of two processor to advertise an in-line static mixer, the other being the Flournoy Green Tech processor. The large scale Denami 600 processor guaranteed ASTM quality biodiesel.

If small scale biodiesel is going to be widely viable, there must be advancements made in the processing technology. Currently, biodiesel is made by the mixing of a source of triglycerides with alcohol and a catalytic base in order to complete the transesterification process yielding biodiesel and glycerin. All of the catalyst used in the reaction is retained in the biodiesel and glycerin. Some of the processors available have a methanol recovery device on them that allows the user to extract the unused methanol. There is no such device for the recovery of the catalyst. A catalyst is any substance that is used in a reaction to lower the activation energy needed for the reaction to take place, but the catalyst itself is not used in the reaction. Theoretically, one should be able to recover all of the catalyst but into the biodiesel; however, the current catalysts, KOH and NaOH, are dissolved into the oil/methanol mixture making it extremely difficult to recover. Realizing this information, we decided to look into a catalyst that can be used for the transesterification of oil that will not be dissolved into the biodiesel. The answer to this need is the use of a solid state catalyst.

In a typical transesterification reaction, there are about 5 grams of potassium hydroxide used per liter of oil. So, for every 100 liters of oil you have you will use, and not be able to reclaim, about 50 grams of catalyst. Since the catalyst should be able to be reused, theoretically you are wasting that 50 grams of catalyst (per 100 liters of oil). Wasted catalyst equals wasted money. But if there was a catalyst that did not dissolve into solution, you could reclaim it and use it again without wasting the catalyst. If there is a solid state catalyst out there that can be used at room temperature to complete the transesterification process and there is a way to incorporate that catalyst into the biodiesel reactor, there is a strong opportunity to save money.

METHODS AND MATERIALS

Introduction

A strong need has been identified for the use of a solid state catalyst in the transesterification process for biodiesel. Our experiments are divided into two separate groups. This first set of experiments was carried out in order to acclimate our team to making simple biodiesel. The first set allowed our team to overcome the learning curve for making biodiesel, so we were able to accurately test our other variables. In addition to overcoming the learning curve, the first set of experiments was used to determine the feedstock and alcohol that will be used for all future experiments. The second set of experiments was done in order to test for solid state catalysts. More specifically, in the second set we are testing different transition metal oxides and hydroxides to quantify their catalytic properties in the transesterification process. The transition metal oxides and hydroxides being tested were those made available to us by the James Madison University Chemistry Department.

Overcoming the Learning Curve

This first set of experiments performed was mainly for our benefit to become familiar with the traditional biodiesel processing procedures. From this set we determined on a visual basis to use soybean oil as our feedstock, methanol as our alcohol, and potassium hydroxide as our traditional catalyst.

Catalyst Options Analysis

The catalyst option analysis set of experiments were performed in order to determine a possible solid state catalyst. The options analysis is done by testing 8 different solid state catalyst candidates at the same time. The experimental procedure for this analysis is as follows.

Materials

- Ten (10) of the following:
  - 120mL flasks
  - Identical stir plates
  - Stir bars
  - Rubber stoppers
  - 50mL centrifuge tubes
- 750mL soybean oil
- 150mL methanol
- X number of moles of catalyst (refer to Table 1)

Table 1: calculates the number go grams of catalyst needed for the reaction based on molecular weight. For an increased opportunity for success, the normal ratio of catalyst to oil has been doubled.

mL of Oil/Sample	75
Liters of Oil/Sample	0.075
Moles of Catalyst/L Oil	0.089

Catalyst Option	Molar Mass (g/mol)	Moles/Sample	Grams/Sample	(Grams/Sample)*2
Potassium Hydroxide	56.11	0.006675	0.37453425	0.7490685
Calcium Hydroxide	74.09	0.006675	0.49455075	0.9891015
Cobalt Oxide	74.93	0.006675	0.50015775	1.0003155
Copper (II) Oxide	79.55	0.006675	0.53099625	1.0619925
Magnesium Hydroxide	58.32	0.006675	0.389286	0.778572
Manganese (IV) Dioxide	86.94	0.006675	0.5803245	1.160649
Niobium Oxide	265.81	0.006675	1.77428175	3.5485635
Barium Hydroxide (octahydrate)	315.46	0.006675	2.1056955	4.211391
Lead Oxide	239.2	0.006675	1.59666	3.19332

Procedure

1. Thoroughly clean all glassware, stir bars, and rubber stoppers. Make sure this equipment is dry before starting the experiment.
2. Set up the 10 stir plates each with a flask containing a stir bar
3. Add 75mL of soybean oil to each flask
4. Add 15mL of methanol and cover flask with rubber stopper

5. For each catalyst, weight out the required grams as stated in Table 1. Remove the rubber stopper, add the catalyst to the oil/methanol mixture, and return stopper
6. Repeat Step 5 for each catalyst
7. Prepare another sample of potassium hydroxide (the two KOH samples serve as controls)
8. Turn on all stir plates to their highest setting
9. Let samples run for 24 hours at room temperature
10. Pour 40mL of the mixture into a centrifuge tube
11. Repeat step 10 for each catalyst
12. Centrifuge for 1-2 minutes

Results

The two potassium hydroxide controls appear to have run to completion. There is a 5mL layer of glycerin that has formed at the bottom of the centrifuge tube of each control. The only solid phase catalyst that formed a substantial layer of glycerin at the bottom was barium hydroxide. The barium hydroxide had a 5mL layer of glycerin at the bottom, followed by a layer of barium hydroxide, finally followed by a layer of biodiesel. The barium hydroxide appears to have run to completion at room temperature; however, it is necessary to run the ASTM test on the gas chromatogram in order to tell for sure. It should be noted that calcium hydroxide also formed a small, approximately 1mL, layer of glycerin as well. We are not using this catalyst for further tests due to its poor results.

Conclusions

Barium hydroxide appears to serve as a solid state catalyst for the transesterification of biodiesel. After two more trials of the barium hydroxide, the results were the same. There was the same 5mL layer of glycerin, which was equal to the control. The second two trials were not centrifuged and the glycerin settled out via gravity. The glycerin, barium hydroxide, biodiesel layer order remained the same; however, since the mixtures were not centrifuged, the barium hydroxide layer was less dense and, as a result, slightly thicker. This research provides hope for the advancement of small scale biodiesel reactors where the traditional catalysts will be replaced with a reusable solid state catalyst.

Future Directions

The research from this summer is going to be continued on into a senior thesis. In this thesis, we are going to attempt to embed barium hydroxide, the solid state catalyst that appeared to work at room temperature, onto a static mixer. This catalyst embed mixer will solve both problems discussed earlier and will be on single device that can be modified to fit onto any small scale biodiesel processor. We are also going to be running samples of the biodiesel made from this device and from other sources through a gas chromatogram using the ASTM test for free and total glycerin. This will provide a quantitative value for us to use to evaluate the device. In addition to testing our samples, multiple small scale biodiesel producers from the Shenandoah Valley are interested in having us test some samples of their biodiesel. Not only will that give them valuable information, it will also give is data to compare our samples against.

We have been contacted by the Department of Engineering at James Madison University and there are five engineering students who are interested in taking over the project after our team has graduated. If we are not able to actually embed the catalyst into metal to make the static mixer, they will have another year to figure it out. It has also recently been brought to our attention that a business major is interested in the project and looking at it from a business point of view. This project has numerous opportunities to grow after our original team has graduated.

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Biodiesel Safety and Recommendations, Procedure Manual, and ASTM Biodiesel Standard Testing Analysis

Shenandoah Agricultural Products

Parker Helble
Summer 2012

This document gives a general safety summary for small-scale biodiesel production and makes recommendations specific to Shenandoah Agricultural Products. The standard operating procedure for Shenandoah Agricultural Products is included, along with a visual accompaniment. Finally, each ASTM biodiesel standard test is analyzed.

Contents

Safety

Basic Safety and Precautions

- Perform reactions in an outdoor or well ventilated area
- Keep all chemicals labeled and stored properly (see MSDS sheets for specifics)
- Know location of safety wash station and extinguishers before handling any chemicals
  - Safety wash station: shower, eye wash
- Keep MSDS sheets on hand
- No smoking within 50 feet of facility
- Do not keep oily rags around, as they can spontaneously combust
- Have access to running water
- Have access to a telephone for emergencies
- Do not eat or drink in the facility
- Do not use chemical glassware as a drinking vessel
- Keep an extra set of clothing nearby in case of any accidents
- Have a drainage system for containment of any spills
- Be sure that methanol is stored in grounded outdoor tanks

Safety Gear and Appropriate Apparel

- Safety glasses/goggles
- Close-toed shoes
- No loose or baggy clothing
- Wear long pants (and shirt if possible)
- Hair tied back (if applicable)
- No loose jewelry (bracelets, rings, earrings, etc.)
- Absorbent material for spills
- Broom and dustpan for broken glass
- Vinegar spray bottle for lye spills
- Shower
- Eye wash station
- Safety gloves (latex)

Reagents

Methanol Safety

- Always wear eye protection and gloves when handling methanol
- Wearing long clothing is highly recommended
- Do not allow contact with skin

- Use methanol in highly ventilated area, as overexposure to higher concentrations can cause damage to the body
- Avoid inhalation
- Do NOT ingest methanol – ingestion can cause blindness or death
- Methanol is highly flammable – do not use around an open flame
- Clean up any spilled methanol immediately

Figure A1: Methanol in Milk Jug

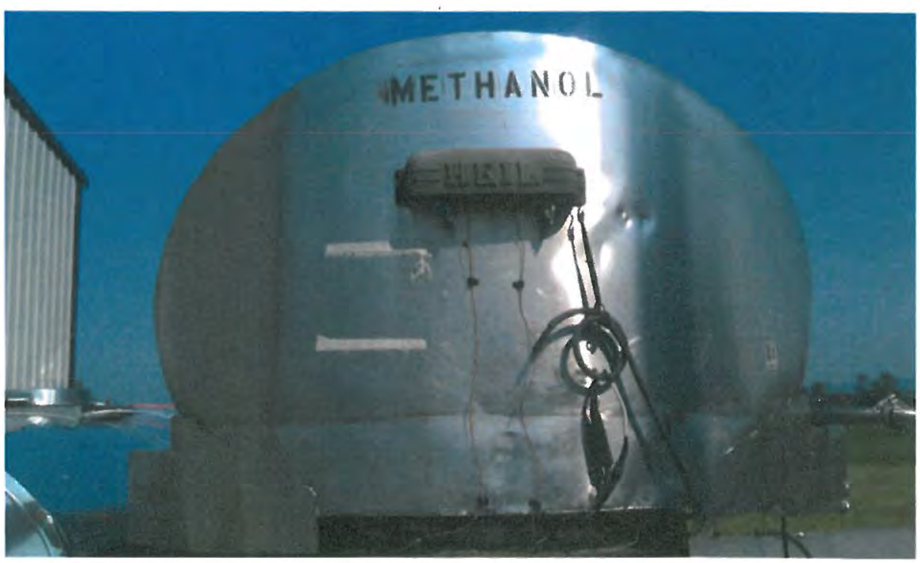

Figure A2: Methanol in a Grounded Outdoor Tanker

Potassium Methylate (in Methanol) Safety

- Always wear eye protection and gloves when handling potassium methylate
- Unstable - Keep out of contact with water or moist air
- Do NOT ingest potassium methylate
- Highly corrosive - do not allow contact with skin
- Do not inhale
- Prolonged contact with skin can cause dermatitis- avoid exposure

Figure A3: Potassium Methylate Barrel

Figure A4: Potassium Methylate Jar for Testing

Figure A5: Potassium Methylate Jar for Testing

Hydrochloric Acid (HCl) Safety

- Hydrochloric acid is a strong acid, and therefore very corrosive
- Keep out of contact with skin
- Always wear eye protection and gloves when handling hydrochloric acid
- Do not ingest
- Do not inhale

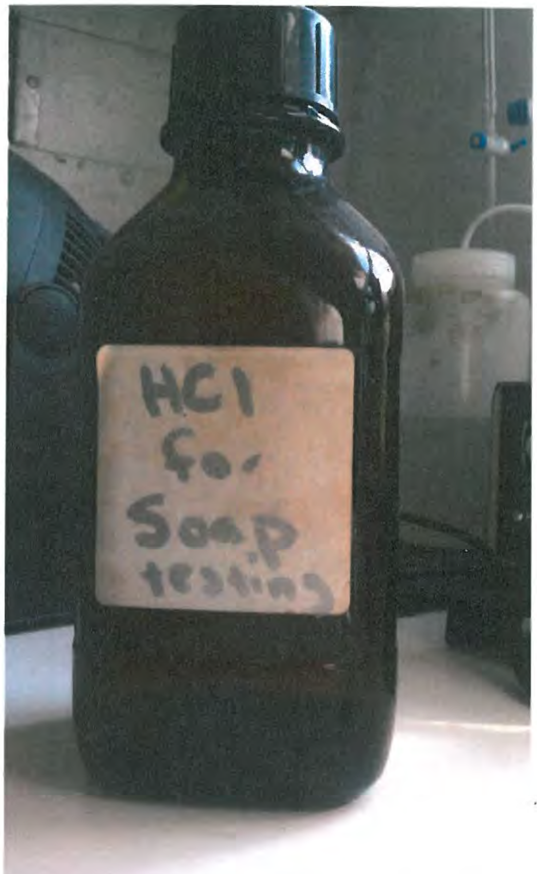

Figure A6: Hydrochloric Acid
in Jar for Testing

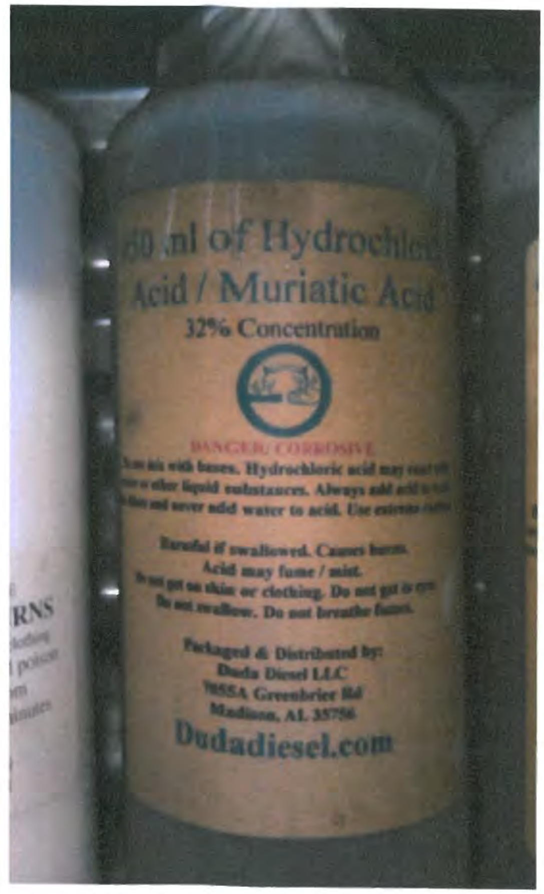

Figure A7: Hydrochloric Acid
Stock Solution

Sodium Hydroxide (NaOH) and Potassium Hydroxide (KOH) Safety

- NaOH and KOH are corrosive
- Always wear eye protection and gloves when handling NaOH or KOH
- Keep a spray bottle with vinegar nearby when handling NaOH or KOH
- Flush any skin that comes into contact with NaOH or KOH thoroughly with water
- Do NOT ingest NaOH or KOH
- Keep away from water
- Keep away from aluminum – explosive hydrogen gas can occur
- Avoid inhalation – use a respirator or dust mask (elbow length gloves and chemical resistant apron also recommended)

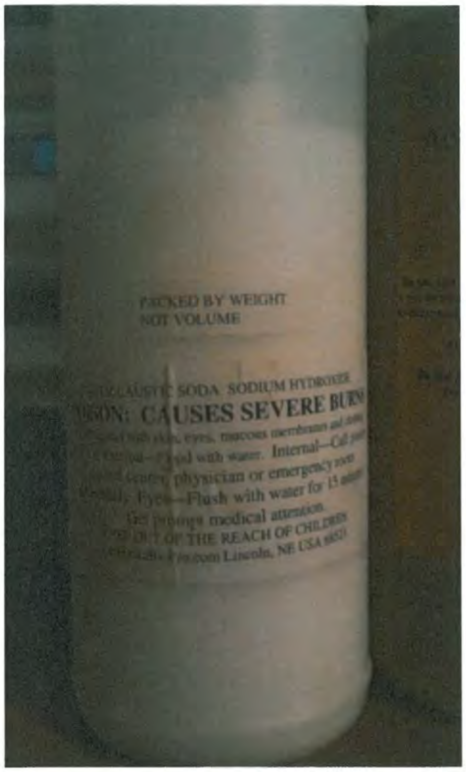

Figure A8: Solid Sodium Hydroxide Crystals

Figure A9: Sodium Hydroxide Solution for Titration Test

Isopropyl Alcohol Safety

- Always wear eye protection and gloves when handling isopropyl alcohol
- Keep out of contact with skin
- Avoid inhalation
- Keep away from open flames
- Use in a highly ventilated area
- Do NOT ingest
- Keep container closed when not in use

Figure A10: Isopropyl Alcohol Barrel

Figure A11: Isopropyl Alcohol Graduated Cylinder for Testing

Acetone Safety

- Always wear eye protection and gloves when handling acetone
- Highly flammable in both vapor and liquid forms – keep away from heat, sparks, and open flames
- Do NOT ingest
- Keep out of contact with skin
- Keep container closed when not in use
- Do not pressurize barrel
- Use in a highly ventilated area

Figure A12: Acetone Barrel

Toluene Safety

- Always wear eye protection and gloves when handling toluene
- Do NOT ingest
- Avoid inhalation
- Keep away from heat, sparks, and open flames
- Keep container closed when not in use
- Use in a highly ventilated area
- Do not pressurize barrel

Figure A13: Toluene Barrel

Phenolphthalein Safety

- Do not material come into contact with eyes
- Do not ingest
- Do not inhale
- Keep out of contact with skin

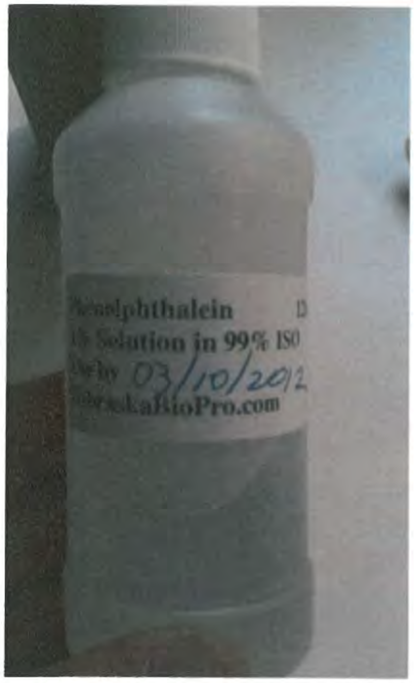

Figure A14: Phenolphthalein Stock Solution

Figure A15: Phenolphthalein Bottle With Dropper

Bromophenol Blue Safety

- Keep out of contact with skin
- Do not ingest
- Do not inhale
- Do not let material come into contact with eyes

Figure A16: Bromophenol Blue Stock Solution

Figure A17: Bromophenol Blue Storage Container

Citric Acid Safety

- Always wear eye protection and gloves when handling citric acid
- Citric acid is a weak acid, but is still corrosive
- Keep out of contact with skin
- Do not ingest or inhale

Sulfuric Acid (H2SO4) Safety

- Always wear eye protection and gloves when handling sulfuric acid
- Sulfuric acid is a strong acid, and is therefore very corrosive
- Keep out of contact with skin
- Do not ingest or inhale

Figure A18: Sulfuric Acid Barrel

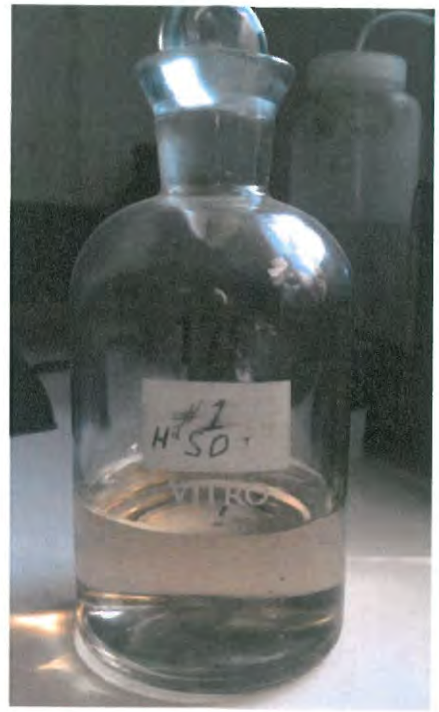

Figure A19: Sulfuric Acid Bottle for Testing

Phosphoric Acid (H3PO4) Safety

- Always wear eye protection and gloves when handling phosphoric acid
- Phosphoric acid is a strong acid, and is therefore very corrosive
- Keep out of contact with skin
- Do not ingest or inhale

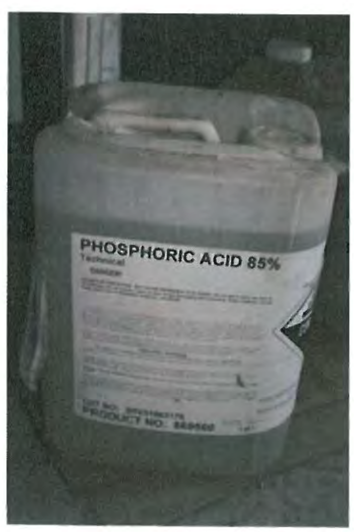

Figure A20: Phosphoric Acid Jug

Figure A21: Phosphoric Acid Bottle for Testing

Eastman BioExtend 30 Antioxidant Solution Safety

- Always wear eye protection and gloves when handling solution
- Do not inhale
- Do not ingest
- Flammable and combustible – keep away from sparks and open flames
- Use in a highly ventilated area

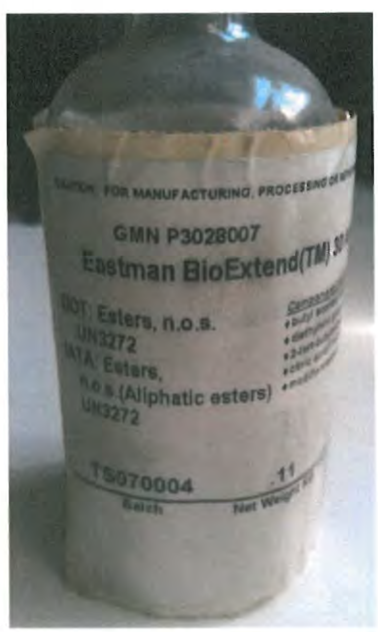

Figure A22: Eastman BioExtend 30 Antioxidant Solution Container and Label

Other Chemicals

Dawn Detergent

- Do not ingest
- Prolonged contact with concentrated material may dry or irritate skin
- Do not let material come into contact with eyes

Figure A23: Dawn Detergent Container

Greased Lightning

- Do not ingest
- Do not inhale
- Skin irritation may occur from prolonged use
- Do not let material come into contact with eyes

Figure A24: Super Strength Greased Lightning Container

Gojo Hand Cleaner

- Do not let material come into contact with eyes
- Do not ingest

Figure A25: Gojo Hand Cleaner Container

Safety Recommendations

- Float alarm/sensor for tanks
- Fix wooden shelf next to computer
- Fix plastic wash rack/shelf by sink
- Locked fireproof chemical cabinet (under sink/test area if possible)
- Safe procedure for refilling outside methanol tanks
- Fix the potassium methylate barrel situation
- Label ALL chemical containers
- Keep fire extinguishers up to date

Figure A26: Fire Extinguisher

Figure A27: Expired Fire Extinguisher Tag

- Remove non-biodiesel related assets from building to minimize loss in the event of facility destruction
- Add an employee locker where non-biodiesel equipment is removed
- Have employees keep extra set of clothes here

- Storage for personal items (food, drink, everything that shouldn't be kept near chemicals)
- Purchase several pairs of safety glasses and designate a storage area for them
- Build emergency shower and eyewash station
- Purchase a label-maker
- Create fire escape plan and designate meeting area 250 feet from facility in case of emergency
- Issue a copy of this document to each employee in the facility
- Create recycling system for waste and ensure proper disposal for chemical containers
    - Paper
    - Plastic
    - Glass
    - Metal
- Post emergency numbers near telephone
- Keep all outdoor portions of the facility locked or fenced to prohibit unauthorized access to facility and facility equipment
- Consolidate all large containers of chemicals into one area relatively separate from the main facility and keep small quantities of each chemical in the lab area for testing. When a chemical is depleted, it can be replenished using the large reserve containers.
- Post proper warning labels on outdoor methanol tanks
- Do not mix two different batches of the same type of chemical.
  Ex: The large black barrel of acetone is sometimes poured into the small blue jug, which is a different brand of the chemical. This creates unknown and unaccounted for changes in concentration/molarity.

Figure A28: Univar Acetone

Figure A29: Crown Acetone Jug

Biodiesel Production Procedure

This procedure was originally written by Josh Leidhecker. Updated version compiled by Parker Helble.

If you aren't sure what something in the procedure below looks like, refer to the **Procedure Visual Accompaniment**.

Pre-Production

1. Check WVO tank drain located just inside roll-up door. Drain out daily any water or emulsified oil.
2. Check temperatures on incoming tanks – WVO tank should be 120°-130° Fahrenheit
3. Open Methanol valves on tanker.
4. Make sure you have enough Nitrogen to get through the day.
5. Switch manual valves to the vertical position recirculation mode
6. Turn pump number 2 counterclockwise to the "A" position labeled "WVO". Circulate for 10 minutes.
7. Take 100 mL sample from the small valve next to the filter housing on the WVO tank.
8. Check glycerin levels in settling tanks – drain if necessary
9. Drain water from the bottom of the two large settling tanks – "preheat" and "washed biodiesel" (between two hoses)

Water Test and Titration

1. Put 50 mL of the sampled oil into a 100 mL beaker
2. Weigh on small "Black Box" scale before heating – note the starting mass on oil log
3. Heat to 220° Fahrenheit until the bubbling stops – this may take a while
4. Weigh heated sample – note the finishing mass on oil log
5. **Subtract the mass of the beaker from the start mass and finish mass**, then use the following equation to calculate water content as a mass percentage:

$$H_2O\% = \frac{start\ mass - finish\ mass}{start\ mass} * 100$$

Note: water mass percentage must be less than 1% for the oil to react properly

1. Place 10 mL Isopropyl Alcohol in a 50 mL beaker on the stir plate.
   Note: The burette on the right side of the stir plate is filled with Isopropyl Alcohol.

Additional Isopropyl Alcohol can be found in the graduated cylinder covered by a beaker and the black barrel on the floor (usually beneath the main switchboard, sometimes below the printer).

2. Place either a long or short stir bar into the beaker and turn stir on (no higher than 3)
   Note: Stir bars are located on the wall next to the WVO funnel.
3. Add 2 or 3 drops of phenolphthalein indicator to the beaker.
   Note: Indicator is located in the small yellow box. Additional indicator solution is located in the cardboard tube next to the small yellow box.
4. Add a few drops of potassium hydroxide titration solution until the beaker turns purple – it should only take a 2 or 3 drops.
   Note: Potassium hydroxide titration solution is in the burette on the left hand side of the stir plate connected to the clear plastic bottle.
5. Using a 3 mL pipette, add 1 mL of oil from the heated sample (used in the water test above) to the beaker.
6. Zero out the burette of potassium hydroxide titration solution by squeezing the plastic bottle connected to it.
7. Add potassium hydroxide titration solution to the beaker until the solution in the beaker turns pink for 30 seconds.
   Note: The color change occurs very suddenly, so be sure not to add the potassium hydroxide titration solution too quickly – you should be able to see the individual drops being added to the beaker.
8. Record the volume of potassium hydroxide titration solution that was used on the oil batch log.
9. Repeat steps 1-8 three more times – the computer will take the average of all four values automatically.
10. Clean up the testing area and any used glassware.

Fill Reactor With WVO

1. Check that all exit valves are closed: "bio out" #7B, "glyc out" #7A.
2. Change manual valves on the WVO tank to the horizontal fill position.
3. Open reactor vent #6 (turn counterclockwise).
4. Open WVO valve #1 (turn clockwise).
5. Turn WVO pump on #2a until the top mass indicator reads 1100 kg.
6. Close WVO valve #1 (turn counterclockwise).
7. Enter actual mass reading from the top indicator into the computer.

Fill Reactor With Methanol

1. Open Nitrogen valve to tanker (valve number 4).
2. **For first stage only**: Turn on reactor vent #6 (turn counterclockwise).
3. Turn the reactor circulator on (green button).
4. Refer to the computer process log for the amount of methanol to be used in the first stage of the reaction.
5. Open methanol valve #3 (turn clockwise).
6. Pump methanol using valve #2B until the desired set point is achieved on the top mass indicator (refer to computer process log for value).
7. Close Methanol valve #3 (turn counterclockwise).
8. **For first stage only**: Turn off reactor vent #6 (turn clockwise).
9. Record actual mass readout of the top mass indicator on the computer process log.
10. Close Nitrogen valve to tanker (valve number 4).

Fill Potassium Methylate Vessel

1. Note starting mass readout of bottom mass indicator.
2. Turn "kmeoh in" valve #4 on (turn clockwise).
3. Make sure yellow and blue valve handles on the potassium methylate barrel are open.
4. Set Nitrogen pressure regulator between 5 and 7 psi. DO NOT EXCEED 8 PSI.
5. Open Nitrogen valve #1 labeled "koh".
6. Fill to desired level on the bottom mass indicator (refer to computer process log for calculation).
7. Turn "kmeoh in" valve #4 off when desired level is achieved (turn counterclockwise).
8. Shut off Nitrogen valve #1 labeled "koh".
9. Record bottom mass indicator actual readout in the computer process log.
10. Close both the yellow and blue valve handles on the potassium methylate barrel.

Inject Potassium Methylate for 1st Reaction Stage

1. Close reactor vent #6 (turn clockwise).
2. Set Nitrogen pressure regulator to 7-8 psi
3. Open Nitrogen pressure valve #2 labeled "koh into mix".
4. Open valve "kmeoh out" #5 to release potassium methylate into the reactor (turn counterclockwise). Dispense 5 kg, close valve #5, wait 30 seconds, and repeat until the bottom indicator displays the target mass.

Note: If the potassium methylate does not leave the vessel (if the number on the bottom indicator does not decrease) within 5 minutes, tap on solenoid valve #9 – it sometimes sticks.

5. Close "kmeoh out" valve #5 when target mass is achieved.
6. Close Nitrogen pressure valve #2 labeled "koh into mix".
7. Record actual mass readout of the bottom indicator in the computer process log.
8. Record reaction start time and temperature in the computer process log.

React 1st Stage Fuel

1. Circulate reactor for 20 minutes. Turn off with red button labeled "ignition stop".
2. Using a plastic graduated cylinder, take a 100 mL sample after 10 minutes to verify the reaction is working – if there is no clear separation in the sample after 10 minutes of settling, refer to troubleshooting guide.
3. Note results in computer process log.
4. Pour graduated cylinder contents into blue WVO funnel next to sink. Wash graduated cylinder with soap.
5. Take another 100 mL sample before you stop circulation – this time with the 100 mL glass graduated cylinder.
6. Turn off reactor circulation pump with the red button labeled "ignition stop" on the main switchboard.
7. Note the time on the computer process log.
8. Allow the sample in the glass cylinder to settle for 20 minutes. When there is a sharp line dividing two different liquids, continue procedure in next section.
9. Start up the centrifuge – see startup instructions.

Decant Glycerin

1. Calculate percent of weight to decant based on the 100 mL sample in the glass graduated cylinde
2. Calculate target mass readout on process log for top indicator.
3. Close reactor vent #6.
4. Open Nitrogen pressure valve #3 labeled "reactor" all the way to pressurize the reactor.
5. Let pressure build for 2 minutes.
6. Open glycerin out valve #7A – if the top indicator number does not go down close the valve, wait, and try again.
7. Drain to calculated target mass reading on top indicator.

8. Turn off glycerin out valve #7A, but do NOT turn it past the vertical position to bio out #7B.
9. Turn off Nitrogen pressure valve #3 to reactor – this valve takes a little longer to actuate, so compensate for this (turn it off a bit early).
10. Record actual mass readout from top indicator on computer process log.

React 2nd Stage Fuel

1. Turn on the circulator (green button)
2. Check to make sure the outside Nitrogen valve is on
3. Open the "koh into mix" Nitrogen valve #2
4. Open the "kmeoh out" valve #5 on the main switchboard
   Note: Open every 30 seconds, 1 kilo at a time.
5. Close "kmeoh out" valve #5
6. Close the "koh into mix" Nitrogen valve #2
7. Note the time in the computer process log
8. Clean any used glassware
9. React for 20 minutes (if high, go 30 minutes)
10. Take 100 mL sample before turning off reactor
11. Turn off reactor
12. Settle for 15-20 minutes

Quality Test – Complete Reaction 27-3 Test

1. Use pipette to transfer the solution from the sample into two 15 mL centrifuge test tubes. Transfer 12 mL to each test tube.
   Note: Test tubes for the centrifuge are located beneath the drying rack by the sink.
2. Place both test tubes in the centrifuge and turn on for 15 minutes
   Note: The centrifuge must be balanced to operate properly. This means that both test tubes must have the same amount of liquid, so adjust accordingly.
3. Place a 50 mL beaker on the stir plate
4. Place the ½ inch long stir bar in the beaker
5. Fill the beaker with 27 mL of methanol from the milk jug on the shelf
6. Use a 3 mL pipette to take 3 mL of solution from the top of one of the test tubes – put this into the 50 mL beaker
7. Turn on mixer
8. Mix for 60 seconds

9. Stop the mixer and remove the stir bar
10. Hold up to see the bottom of the beaker
11. Look for small beads of glycerin to form in the first 60 seconds
12. If test is clear of glycerin proceed to next step. If not, refer to troubleshooting manual.

Decant Biodiesel and Final Glycerin

1. Make sure reactor vent #6 is closed on the main switchboard
2. Make sure the centrifuge does not have any fuel running through the sight glass – there needs to be space in the final settling tank for the current batch to push through.
3. Set Nitrogen regulator to highest setting – use the yellow valve next to the Nitrogen control box
4. Open Nitrogen valve #3 to reactor
5. Let pressure build in the reactor for 3 minutes
6. Open "biodiesel out" valve #7B on the main switchboard
   Note: If the mass readout on the top indicator does not decrease, you need more pressure in the reactor – close valve for a little longer.
7. Push biodiesel out into settling tanks until mass readout on indicator stops decreasing (12 kg)
8. Turn valve #7 on the main switchboard clockwise to the #7a glycerin out position
9. Allow the remaining mass to exit the reactor into the glycerin settling tank
10. Turn valve #7 to center off position (turn counterclockwise)
11. Turn off Nitrogen valve #3 off
12. Turn the yellow valve next to the Nitrogen control box off

Note: There are fail-safe switches which will not allow you to overfill any of the holding tanks. If you overfill a tank the system should shut off the power to the solenoid and a red light will activate on the main switchboard.

Notes on Oil Quality

For most instances we will use a 20-22% addition of methanol to the mix. Typically as the quality of the oil decreases, amount of methanol added increases. As a rough guideline we use the following:

Table 1: Percent Methanol to Add Based on Titration Results

Titration results of:	% of Methanol
1 to 4 mL	20
5 to 8 mL	24
9 to 11 mL	28

Oil with titration results of 12mL and above should be rejected or set aside for additional treatment before transesterification.

Notes on Water Content

Water content should be as close to zero as possible. 1 percent water content may be permissible if the titration results are low. Water leads to soap production, which in turn leads to slow or incomplete reactions and settling. If our first 10 minute sample does not separate, chances are soap formation has caused a stable emulsion. We would need to figure this out in the lab before we attempt a fix in the system. Soap formation could also keep some of the oil from converting to methyl esters which could lead to a failed 27-3 test.

Centrifuge Start-up and Operation

After you start the first stage reaction in the reactor you should direct your attention to the start up of the centrifuge. Once a week, or if there are separation difficulties, the top cover will need to be opened and the machine will have to be taken apart and cleaned. The fuel should be very clean coming through so it will mostly likely only need to be cleaned a few times a year, but should be inspected regularly. We are washing our fuel in two stages; first we are injecting 10% citric acid water into the finished fuel, then removing most of the water with the centrifuge. This first stage does not remove all of the water, so we push the batches of the day through the centrifuge and into the holding tank behind the centrifuge. At the end of the day, the fuel is then diverted back into the centrifuge without the addition of citric acid water. As long as that fuel is clear when observed through the sight glass, it can be passed on through the bottom holding tank and on to the rest of the finishing skid – see finishing skid instructions.

1. Power up green button on the VFD or a remote switch in the control room. The VFD is in the grey box to the left of the centrifuge.

2. The centrifuge will need 10 minutes to get up to speed. The counter on the front should be rotating at 88-92 RPM's
3. Close all biodiesel in valves, including the control valve on the top of the centrifuge.
4. Open prime port on top-threaded plug.
5. Put extra water line from heat exchanger in the top of the centrifuge; inject hot water until the outside is warm to the touch. This step warms up the centrifuge and establishes the liquid ring in the bowl.
6. Once the first batch of the day has been pushed into the settling tanks you can open the valves to the centrifuge. One is located on the back of the settling tanks and the other is the lowest manual stainless valve on the intake manifold. Keep the centrifuge control valve closed until you are ready.
7. Close the loose hose valve on the water intake and open the valve to the venturi injector.
8. Replace the top prime plug.
9. Slowly open the black control valve on top of the centrifuge – watch the exit lines. White water should be coming out of the water port and semi-clear biodiesel should be seen in the sight glass. The water should be 10% of the biodiesel flow.
10. Slowly increase the openness of the control valve – as long as the two exiting liquids remain the same – until it is fully open.
11. Periodically check the sight glass and the exiting water line to see that they are flowing the same way.
12. Run all batches during the shift through the centrifuge with full water.
13. Once finished running batches shut off water valve, bottom biodiesel valve, and centrifuge control valve.
14. Open valve from the holding tank to the manifold before the heat exchanger.
15. Slowly open the centrifuge control valve until you see clear biodiesel in the sight glass and just a little water coming out of the water line. Open all the way.
16. At this time the fuel is recirculating into the holding tank behind.
17. Once the quality of the fuel in the sight glass is satisfactory you can open the valve to direct the fuel into the holding tank below the centrifuge. Then close the valve letting the fuel go back to the settling tank behind.
18. The fuel will start to fill the 70 gallon square tank below the centrifuge.
19. The tank is equipped with level sensors that will control the pump through the rest of the system, but is **NOT** designed to stop the flow of the centrifuge if it is overfilled so this must be watched to make sure that it does not overflow.

Finishing Skid Operation

You have already been introduced to the water injection and centrifuge operation. The rest of the final polishing happens in the coalescing filter (green) and the two ion exchange towers next to the centrifuge. The fuel that has been washed and then run through the centrifuge is held in a 70 gallon tank under the centrifuge. There are level sensors in this tank that turn on and off the PD diaphragm pump. This pump is designed to keep a max pressure of 30 – 50 PSI in the second half of the system. The fuel is passed through a 1 micron water separating filter which catches anything that has been missed by the centrifuge. It then flows up to the top of the first ion exchange tower, then is passed through a second ion exchange tower. The ion exchange material is designed to remove any dissolved water, glycerin, methanol, free fatty acids, etc. that may have been missed by the initial water wash. Waste oil biodiesel contains some contaminants that are hard to remove from the fuel. This is why we are using to washing techniques – wet and dry. It will yield us the highest quality fuel given the low quality feedstock.

Lab Testing and Preparation Procedures

Testing locations for soap and TAN: after mist tank or after citric wash, before filter tubes, in between filter tubes, finished fuel

Soap Test

1. Put at least 100 mL of acetone in a medium sized beaker.
2. Put a large stir crossbar in
3. Put on stir plate and begin mixing
4. Add Bromophenol Blue until the acetone has a bluish tint (usually about 10 drops)
5. Add HCl 1 drop at a time until the solution becomes clear with a yellowish tint.
6. Put the beaker on the scale and tare it.
7. Add 30 grams of biodiesel sample. If the solution now has a blue/green color, go to step 8. If the solution is still yellow or biodiesel-like in color, stop now and record soap content as 0.
8. Your solution is currently blue/green. Record the mass of the biodiesel sample you have added and move the beaker to the stir plate.
9. Begin stirring. Note how much HCl is in the burette, then add HCl until the solution turns back to yellow. Record the amount of HCl remaining in the burette.
10. Calculate soap content by using the following equation:

$$\frac{(mL\ of\ HCl\ at\ finish - mL\ of\ HCl\ at\ start) * .01 * 304{,}400}{mass\ of\ biodiesel\ added}$$

11. Enter your soap content values in the computer to see if they are within the acceptable range.
12. Pour the beaker into the sink and wash all used glassware.

TAN Test

1. Put 125 mL of TAN solution into a medium sized beaker (TAN solution is in the brown glass bottle beneath the testing area)
2. Put a large stir crossbar in
3. Place beaker on stir plate and begin mixing
4. Add 10 drops of Phenolphthalein
5. Turn the mixture pink by adding potassium hydroxide (KOH) slowly – one drop at a time. It should not take more than a few drops.
6. Place beaker on scale, tare, and add 20 grams of biodiesel sample. Record exact mass of biodiesel sample added to the solution.

7. Place beaker back on stir plate and fill the KOH burette to the zero mark
8. Add KOH until the mixture turns pink again, then note the level of the KOH in the burette .
9. Calculate TAN by using the following equation:

$$\frac{final\ KOH\ amount * .1 * 56.1}{mass\ of\ biodiesel\ added}$$

10. Check TAN value against recently calculated TAN values sampled at the same location to be sure everything is still working the way it should be.

Citric Mix

1. The overall concentration is 5 lbs of citric in 250 gallons of water
2. If you like, you can calculate the concentration of the citric in the remaining water when it is time to refill the citric container, but this can get confusing and eventually change the concentration too much. Instead dump the water that remains in the tote when it comes time to refill it, and then add 5 lbs of citric while filling the tote back to 250 gallons.

TAN Solution Mix

1. The brown jug beneath the testing area should be completely empty before mixing a new batch of solution to re-fill it.
2. Once empty, fill with Toluene to the first blue sticker on the jug. (Toluene can be found in a black barrel labeled "Toluene) beneath the printer)
3. Add isopropyl alcohol up to the second blue sticker on the jug. (Isopropyl alcohol can be found in a black barrel labeled "Isopropyl Alcohol 99% Anhydrous" usually beneath the main switchboard or beneath the printer)
4. Add just a bit of distilled water (up to the top of the second blue sticker).
5. Screw cap on and shake well.

Note: Stickers are not even, but levels are only approximations. As long as the level is somewhere on the blue sticker, the solution should turn out fine.

Hydrochloric Acid Mix

1. Measure 249.76 mL (or as close as you can get it) of distilled water and put in a large beaker.
2. Put beaker on scale and tare.
3. Add .28 grams of concentrated hydrochloric acid (HCl, 32%). Concentrated HCl is just outside the lab area on a shelf.
4. Place beaker on stir plate and mix well.
5. Pour into HCl bottle.
6. Wash all used glassware.

Potassium Hydroxide Mix for TAN Test

1. Measure 100 mL of distilled water and put in a medium sized beaker.
2. Measure .62 grams of potassium hydroxide (KOH) flakes (located in a bag just outside the lab).
3. Add flakes to water.
4. Place beaker on stir plate and mix until flakes are dissolved.
5. Pour into the KOH bottle.

Potassium Hydroxide Mix for Titrations

1. If there is some 5% stock solution on the shelf next to the testing area, go to step 2. If there is none left, see instructions in the filing cabinet to make 5% stock solution.
2. Put 450 mL of distilled water in a large beaker.
3. Add 50 mL of the 5% stock solution to the distilled water.
4. Mix well and pour into the KOH bottle.

Lab Experiment: Pretreatment of WVO with Glycerin

Materials

- 100 mL beaker
- 50 mL beaker
- WVO sample
- Recovered glycerin
- Long stir bar
- Phenolphthalein
- Heat/stir plate
- Isopropyl alcohol
- Titration solution
- Short stir bar
- 1 mL pipette
- Thermometer

Temperature Variation Procedure

1. Turn on heat setting on stir plate to "1"
2. Fill 100 mL beaker with 20 mL glycerin
3. Add 60 mL WVO sample to beaker
4. Place long stir bar in beaker, place beaker on stir plate
5. Mix until glycerin and WVO become a single solution

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6. In a separate 50 mL beaker, measure 10 mL isopropyl alcohol
7. Place short stir bar in beaker, place beaker on stir plate
8. Add 3 drops of phenolphthalein indicator to beaker
9. Add 3 drops of titration solution to beaker until it flashes purple

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10. With a pipette, take 1 mL of solution from the 100 mL beaker and add to the 50 mL beaker
11. Record the temperature of the solution when it stabilizes
12. Add titration solution to the 50 mL beaker until it flashes purple and remains for 30 seconds
13. Record the amount of titration solution used
14. Repeat procedure, increasing the heat setting by 1 each time

Time Variation Procedure

1. Fill 100 mL beaker with 20 mL glycerin
2. Add 60 mL WVO sample to beaker
3. Place long stir bar in beaker, place beaker on stir plate
4. Mix for one minute

---

5. In a separate 50 mL beaker, measure 10 mL isopropyl alcohol
6. Place short stir bar in beaker, place beaker on stir plate
7. Add 3 drops of phenolphthalein indicator to beaker
8. Add 3 drops of titration solution to beaker until it flashes purple

---

9. With a pipette, take 1 mL of solution from the 100 mL beaker and add to the 50 mL beaker
10. Add titration solution to the 50 mL beaker until it flashes purple and remains for 30 seconds
11. Record the amount of titration solution used
12. Repeat procedure, increasing the mixing time (step 4) by 1 minute each time

Glycerin Percentage Variation Procedure

1. Fill 100 mL beaker with 10 mL glycerin
2. Add 70 mL WVO sample to beaker
3. Place long stir bar in beaker, place beaker on stir plate
4. Mix until glycerin and WVO become a single solution

---

5. In a separate 50 mL beaker, measure 10 mL isopropyl alcohol
6. Place short stir bar in beaker, place beaker on stir plate
7. Add 3 drops of phenolphthalein indicator to beaker
8. Add 3 drops of titration solution to beaker until it flashes purple

---

9. With a pipette, take 1 mL of solution from the 100 mL beaker and add to the 50 mL beaker
10. Add titration solution to the 50 mL beaker until it flashes purple and remains for 30 seconds
11. Record the amount of titration solution used
12. Repeat procedure, increasing the amount of added glycerin (step 1) by 10 mL and decreasing the amount of added WVO (step 2) by 10 mL each time

Glycerin/WVO Mixing Apparatus

Procedure Visual Accompaniment

Pre production

Figure B1: WVO Tank Drain

Figure B2: Tank Temperature Readouts

Figure B3: Methanol Tanker and Valve

Figure B4: Nitrogen Tanks

Figure B5: Main Switchboard

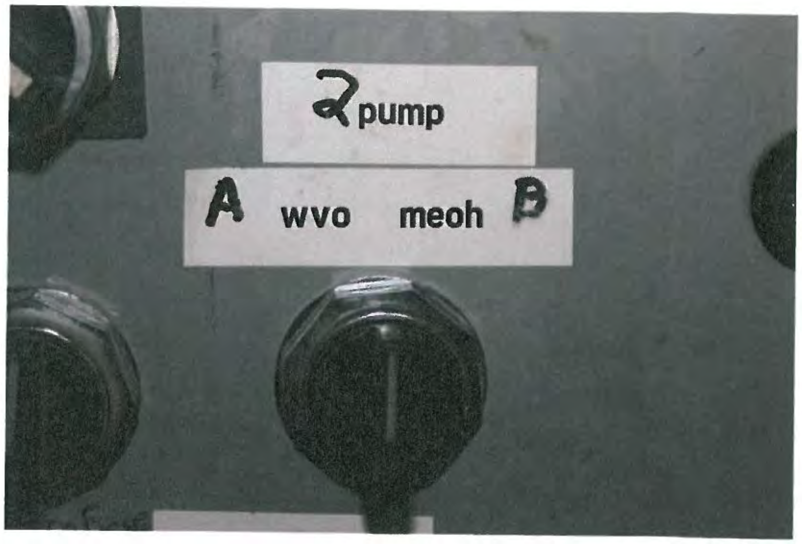

Figure B6: Pump #2A (WVO) and #2B (MeOH)

Figure B7: WVO Sample Valve in Trailer

Water test and titration

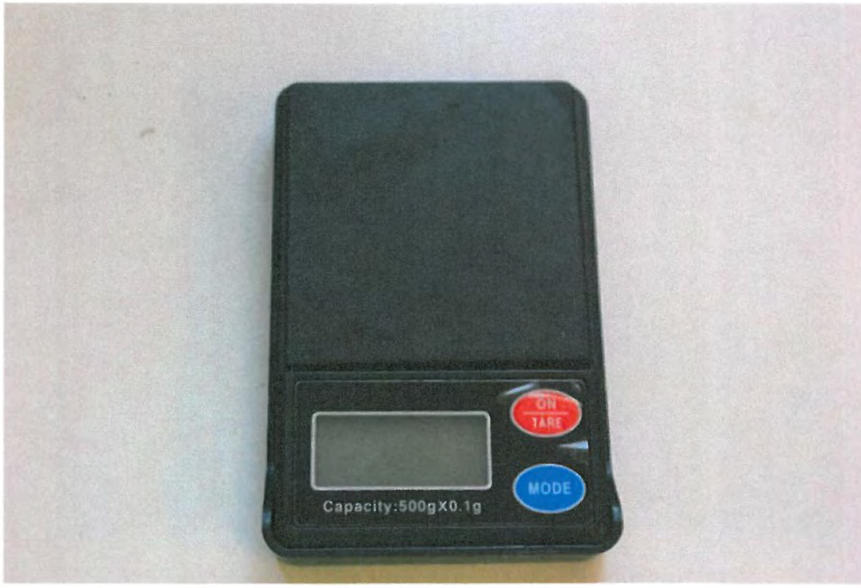

Figure B8: Black Box Scale

Figure B9: Stir Bars

Figure B10: Phenolphthalein Indicator

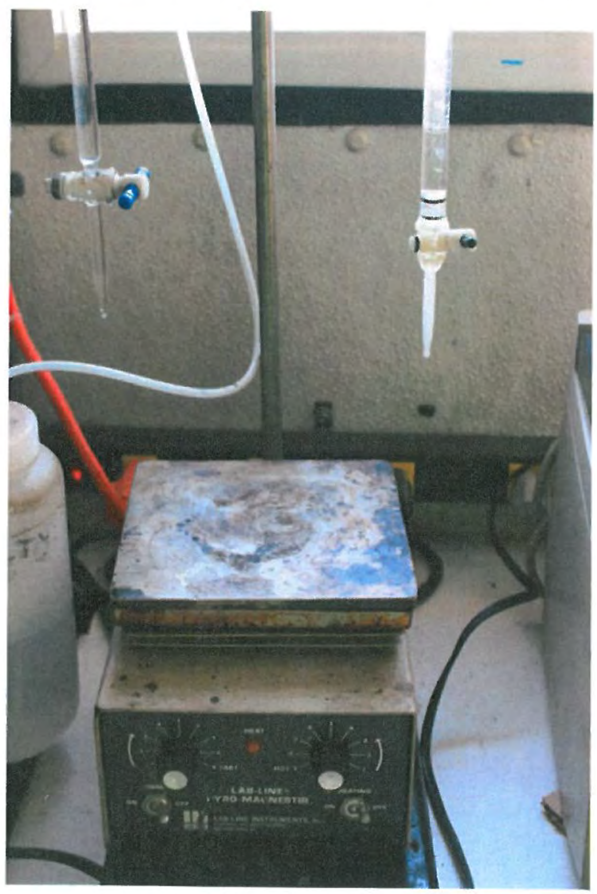

Figure B11: Stir Plate, Potassium Hydroxide Burette (left), Isopropyl Alcohol Burette (right)

Fill reactor with wvo

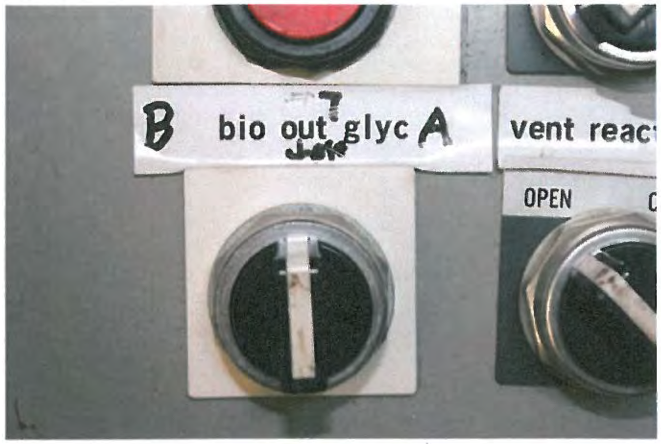

Figure B12: Pump #7A (biodiesel out) and #7B (glycerin out)

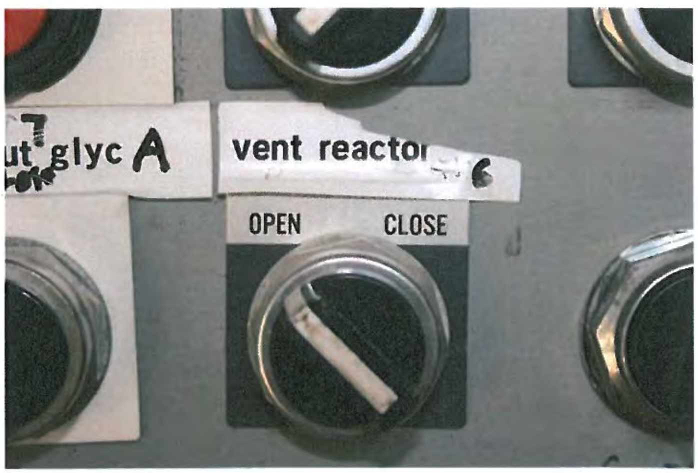

Figure B13: Reactor Vent Valve #6

Figure B14: WVO Valve #1

Figure B15: Mass Indicators for Reactor (top) and Potassium Methylate Vessel (bottom)

Fill reactor with methanol

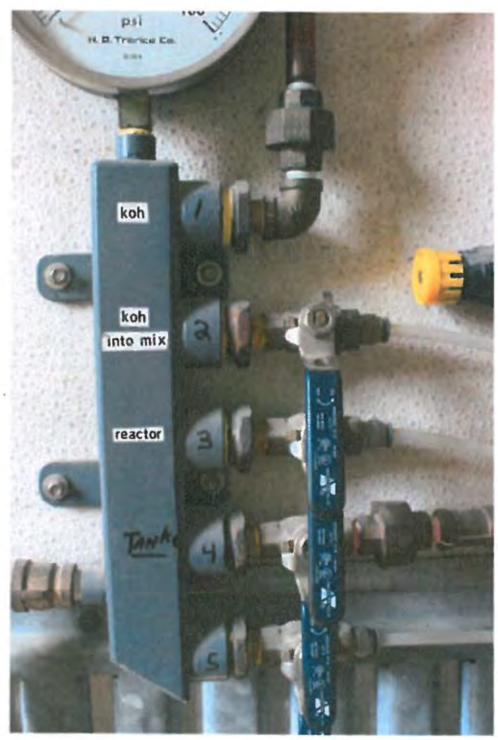

Figure B16: Nitrogen Control Valves #1 (KOH), #2 (KOH into mix), #3 (reactor), #4 (tanker), and #5

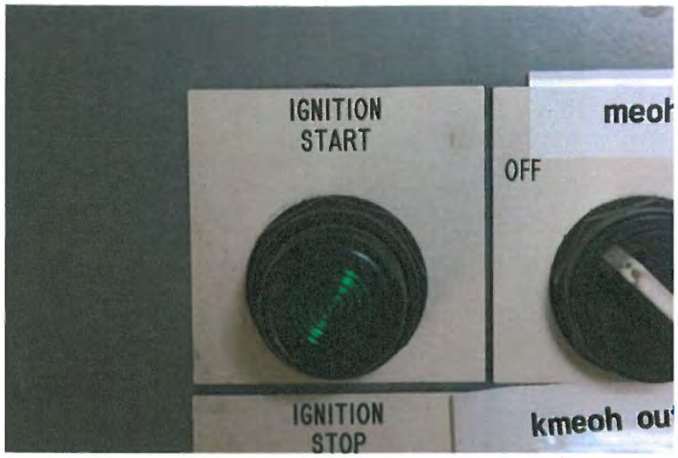

Figure B17: Circulation Button

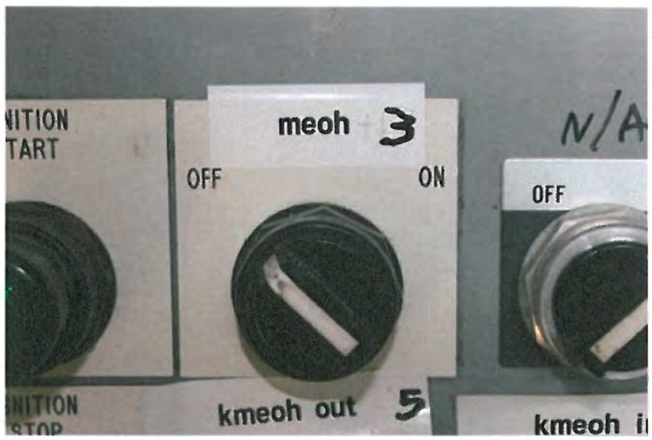

Figure B18: Valve #3 (MeOH)

Fill potassium methylate vessel

Figure B19: Valve #4 (KMeOH in)

Figure B20: Potassium Methylate Barrel, Blue and Yellow Valves

Figure B21: Nitrogen Pressure Regulator

Inject potassium methylate for 1st reaction stage

Figure B22: Valve #5 (KMeOH out)

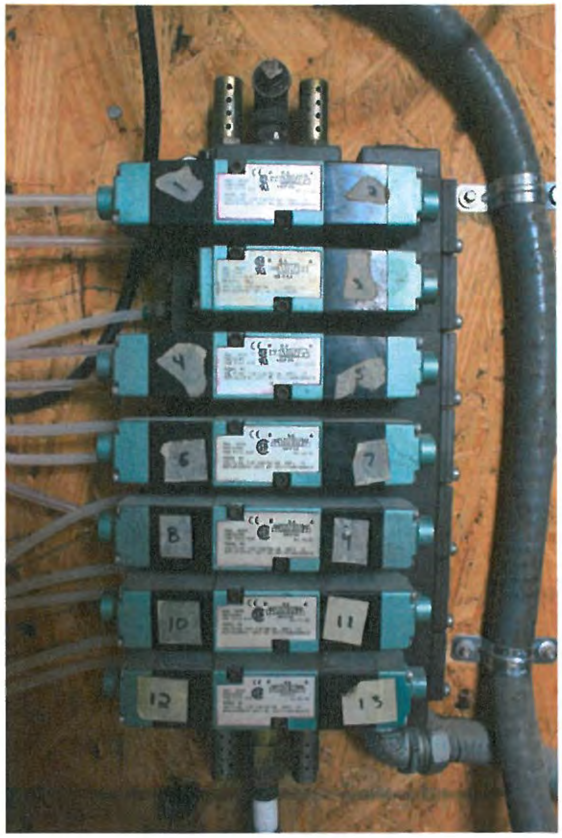

Figure B23: Solenoid Valves

React 1st stage fuel

Figure B24: Reactor Sample Valve

Figure B25: WVO Recycle Funnel

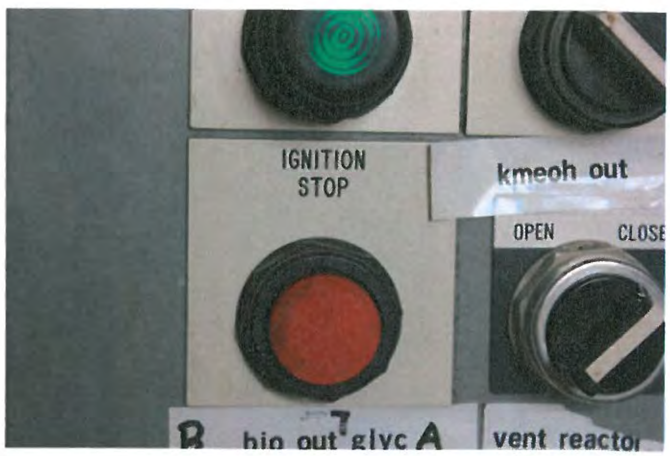

Figure B26: Circulation Stop Button (ignition stop)

Decant glycerin

React 2nd stage fuel

Quality test – complete reaction 27-3 test

Figure B27: Centrifuge Test Tubes

Figure B28: Test Centrifuge

Decant biodiesel and final glycerin

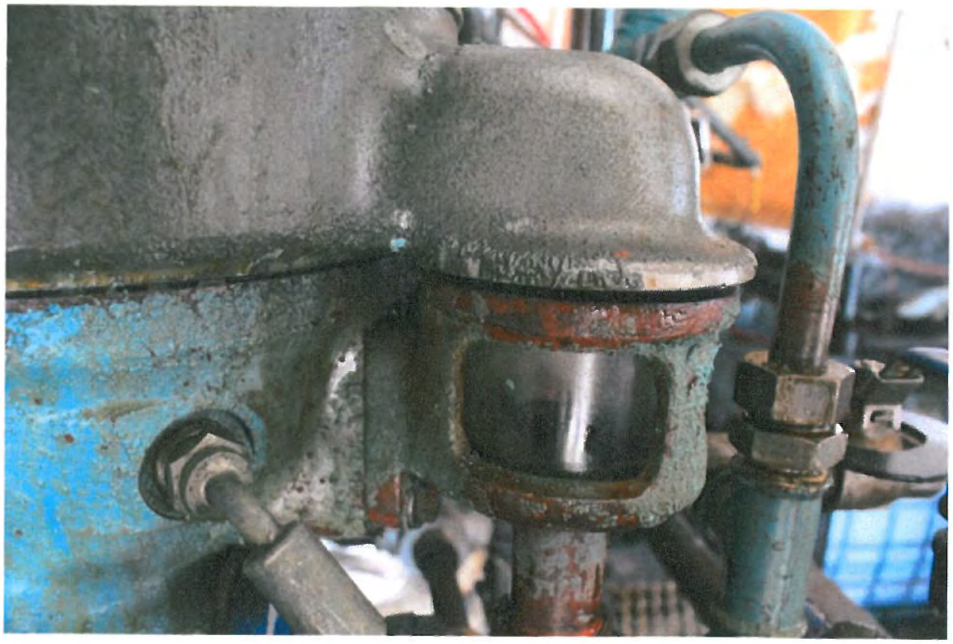

Figure B29: Centrifuge Sight Glass

Figure B30: Nitrogen Pressure Control Valve

Centrifuge Start-up and Operation

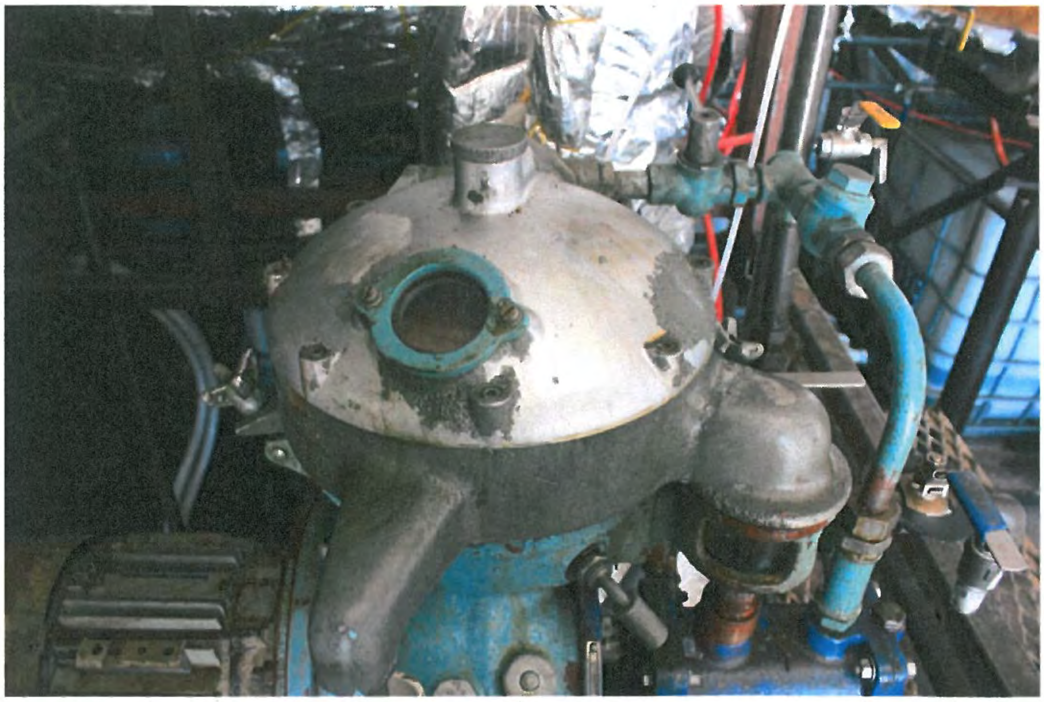

Figure B31: Wash Centrifuge Overview

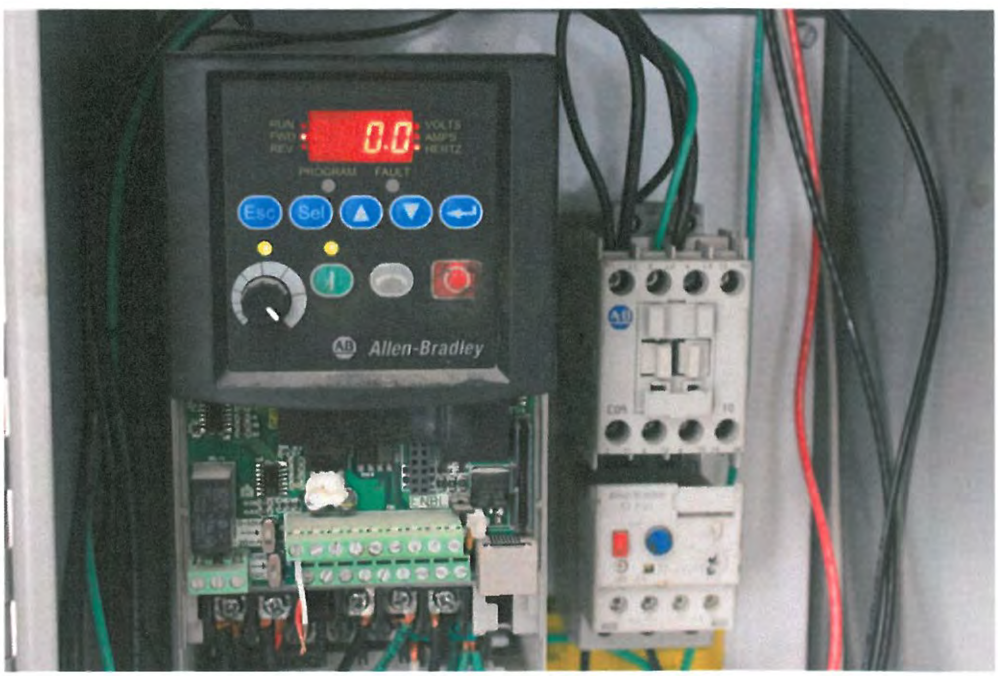

Figure B32: Centrifuge Control Box

Figure B33: Top Threaded Plug in Prime Port

Figure B34: Water Line from Heat Exchanger

Figure B35: Centrifuge Flow Control Valve

Figure B36: Holding Tank Valve

Lab Testing and Preparation Procedures

Soap Test

Figure B37: Stir Crossbar (right)

TAN Test

Figure B38: Brown Glass Bottle for TAN Solution

Citric Mix

Figure B39: Citric Acid Tote Above Wash Centrifuge

Analysis of ASTM Testing Procedures

The current biodiesel standard in the United States is the ASTM Biodiesel Standard D6751-11b (B100 fuel).

Lab Tests

Free Glycerol, Total Glycerol

ASTM D6584-10ae1: Standard Test Method for Determination of Total Monoglyceride, Total Diglyceride, Total Triglyceride, and Free and Total Glycerin in B-100 Biodiesel Methyl Esters by Gas Chromatography

This test quantifies the glycerol content of the biodiesel. Glycerin and mono-, di-, and triglycerides in the finished biodiesel product is not desired. Glycerin can cause problems if the fuel is in storage or can cause fouling in injectors in fuel systems. This test is performed with a gas chromatograph.

Free glycerol limit (max): .02% mass

Total glycerol limit (max): .24% mass

Cole-Parmer; Economical Compact BioDiesel Gas Chromatograph (Free and Total Glycerin) with FID; 115V

$8,500.00

Viscosity

ASTM D445-12: Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

This test identifies the kinematic viscosity of the biodiesel fuel. The dynamic viscosity can be calculated simply by multiplying the kinematic viscosity of the biodiesel fuel by the density of the biodiesel fuel. The viscosity is an important property to determine because it affects handling, storage, and transportation of the fuel.

Limits (at 40 degrees Celsius): 1.9 – 6.0 mm^2/s

CertifiedMaterialTestingProducts.com; Constant Temperature Viscosity Bath, Economy, 115V, 50-60 Hz

$2,639.00

Global; 29L Viscosity Bath w/Round Openings, Advanced Digital Controller

$2,715.00

Flashpoint

ASTM D93-11: Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

This test measures the temperature at which biodiesel fuel forms a hazardous flammable mixture with air. It is one component in measuring the overall flammability hazard of the fuel. The flash point determines which classification of flammability and combustibility is displayed on tankers during transportation.

Minimum temperature: 130 degrees Celsius

General Laboratory Supply; Pensky-Martens Closed Cup Flash Point Tester. Koehler, 115V

$1,838.15

General Laboratory Supply; Pensky-Martens Closed Cup Flash Point Tester. Gas Heated.

$1,946.79

Water and Sediment

ASTM D2709-96(2011)e1: Standard Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge

A centrifuge is used to separate water and sediment from the biodiesel fuel. The test measures the volume of unwanted water and sediment that is contained in the fuel.

Maximum content: .05% volume

LabPlanet.com: Koehler Instrument Oil Test Centrifuge, Koehler K61092 Oil Test Centrifuge W/HTNG 220

$13,830.39

<u>Cloud Point</u>

ASTM D2500-11: Standard Test Method for Cloud Point of Petroleum Products

This test determines the lowest temperature at which the biodiesel fuel can be used, and is specific to each batch produced. A sample of the biodiesel fuel is cooled until the first cloud appears – the temperature of the fuel at this point is the lowest temperature at which the fuel can be used.

There are no established limits for this test, as each batch varies.

Lawler Manufacturing Corporation: Automated Cloud Point Analyzer

Price not listed

<u>Sulfated Ash</u>

ASTM D874-07: Standard Test Method for Sulfated Ash from Lubricating Oils and Additives

This test determines the amount of ash in biodiesel fuel. To determine the ash content, a sample of the fuel is ignited and burned.

Maximum content: .02% mass

Cole-Parmer; Programmable Ashing Furnace, .47 cubic feet, drop down door, 240V

$10,395.00

<u>Total Sulfur</u>

ASTM D5453-09 : Standard Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence

This test quantifies the sulfur content of produced biodiesel fuel by ultraviolet fluorescence. During fuel refining, sulfur can inhibit catalysts, so total sulfur content should be kept minimal in biodiesel fuel. Sulfur can also oxidize to SO_2 (sulfur dioxide) at higher temperatures.

Maximum content: .05% mass

<u>Copper Strip Corrosion</u>

ASTM D130-10: Standard Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test

This test assesses the relative corrosiveness of biodiesel fuel caused by remaining sulfur compounds. A strip of copper is placed into a sample of the fuel and the copper strip is then compared to a standard color chart.

Maximum: No. 3

General Laboratory Supply; Copper Strip Corrosion Test Bomb, Koehler

$620.80

General Laboratory Supply; LPG Corrosion Bomb Heater, L-K Industries (12 V portable or 115 benchtop)

$1,724.95

Cole-Parmer; Koehler ASTM Copper Corrosion Standard

$805.00

Cetane No.

ASTM D613-10a: Standard Test Method for Cetane Number of Diesel Fuel Oil

This test is used to measure fuel ignition characteristics for biodiesel in a compression-ignition type engine. The results of this test are used to match up different engines with different fuels.

Minimum: 47

GE Energy; CFR F5 Cetane

Price not listed

Carbon Residue

ASTM D4530-11: Standard Test Method for Determination of Carbon Residue (Micro Method)

This test measures how likely the biodiesel fuel is produce carbon sediment. A biodiesel sample is heated in an inert environment to ensure that there is no combustion during the test. High amounts of carbon sediment can indicate high residual glycerol in the biodiesel sample.

Maximum content: .05% mass

Cole-Parmer: Koehler Micro Carbon Residue Tester, 230 VAC, 50/60 Hz

$21,144.00

Phosphorus Content

ASTM D4951-09: Standard Test Method for Determination of Additive Elements in Lubricating Oils by Inductively Coupled Plasma Atomic Emission Spectrometry

This test quantifies the amount of phosphorous contained in biodiesel fuel. Phosphorus can lead to corrosion of engine components if concentration is too high. In order for precision statements by ASTM standards to be valid, a sample must be diluted to a range of 1% to 5% biodiesel by mass.

Maximum content: .001% mass

Perkin Elmer Biodiesel Trace Metals Analyzer (ASTM D4951)

Contact for price quote

<u>**Distillation Temperature at 90% Recovery**</u>

ASTM D1160-06: Standard Test Method for Distillation of Petroleum Products at Reduced Pressure

This test determines the range of boiling points of biodiesel at various reduced pressures. A distillation apparatus distills the fuel at a pressure lower than atmospheric pressure, measures the initial and final boiling points, and generates a curve between the two points. Because the boiling point is related to multiple physical, mechanical, and chemical properties of the fuel, the discovery of the boiling point in this test is critical to determine the suitability of the fuel for any given application.

Maximum distillation temperature (at 90% recovery): 360 degrees Celsius

Cole-Parmer Koehler Manual Vacuum Distillation System, 115 VAC, 60 Hz

$13,160.00

<u>**Acid Number**</u>

ASTM D664-11a: Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration

This test is a measure of the remaining acid in the biodiesel fuel and can be determined through titration using indicators. Shenandoah Agricultural Products conducts this test as described in the TAN test section of the procedure.

Maximum: .8 mg KOH/g

Calcium and Magnesium, Combined

ASTM EN14538

This test measures the amount of catalyst cations remaining in the product after the reaction is complete. Calcium and Magnesium may be present in the form of soap or abrasive solids and can reduce time until next service. Samples are analyzed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

Limit (maximum): 5 ppm

Thermo Scientific: iCAP 6000 Series ICP Emission Spectrometer

Price not listed

Sodium and Potassium, Combined

ASTM EN14538

This test measures the amount of catalyst cations remaining in the product after the reaction is complete. Like Calcium and Magnesium, Sodium and Potassium may be present in the form of soap or abrasive solids and can reduce time until next service. Samples are analyzed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

Limit (maximum): 5 ppm

Thermo Scientific: iCAP 6000 Series ICP Emission Spectrometer

Price not listed

Oxidation Stability

ASTM EN14112

This test measures degradation to the biodiesel fuel caused by exposure to oxygen in the atmosphere. This can help determine storage parameters for the biodiesel post-production.

Limit (minimum): 3 hours

Lawler Manufacturing Corporation: Biodiesel Oxidation Tester Model 321-2

Price not listed

Cold Soak Filtration

ASTM D7501-09b: Standard Test Method for Determination of Fuel Filter Blocking Potential of Biodiesel (B100) Blend Stock by Cold Soak Filtration Test (CSFT)

One of the more recently mandated biodiesel tests, this measures the tendency of biodiesel fuel to form a solid precipitate under the condition of extended storage in cold weather. The fuel is cooled to 40 degrees Fahrenheit, and then allowed to return to room temperature without external agitation. The fuel (of volume 300mL) must then pass through a filter under vacuum in less than six minutes in order to meet ASTM requirements.

Limit (maximum): 360 seconds

Lawler Manufacturing Corporation: Biodiesel Cold Soak Filtration Test Model 325-6

Price not listed

Biodiesel-Kits-Online: ColdClear BCC100 Treatment System (5 gpm)

Without Options: $3,428.00

Full Biodiesel Testing Option

As an alternative to testing each standard separately, biodiesel production companies can send a sample of their produced fuel to a lab to be fully tested. The provided example below tests each parameter described in the above sections.

Biodiesel Experts International/Saybolt Laboratories; ASTM D6751 08a Testing

$3,521.00

Home Tests

Methanol Solubility Test (aka 27/3 test)

In this test, 3 mL biodiesel is mixed with 27 mL methanol. If the biodiesel solution dissolves completely in the methanol, then the biodiesel solution does not contain a significant amount of glycerol and can be used as fuel. If the biodiesel solution does not dissolve completely in the methanol, then the biodiesel solution still contains a significant amount of glycerol and requires further treatment before it can be used as fuel.

This test is performed at Shenandoah Agricultural Products with the lab stir plate as described in the procedure.

Reprocess Test

This test reprocesses a sample of biodiesel in place of waste vegetable oil. The small scale reaction process is carried out with low amounts of methanol and catalyst, and then the sample container is examined for glycerin settling. If there is glycerin at the bottom of the sample, this signifies an incomplete reaction during the first reaction process. If a gel forms at the bottom of the container, this signifies full conversion during the first reaction process.

This test can be replaced by the methanol solubility test described in the previous section.

Soap Test

Soap forms as a result of the catalyst reacting with free fatty acids in the waste vegetable oil. An added washing step removes the soap from the biodiesel fuel. This test is a titration type test that determines the soap content of biodiesel fuel. This home test is valid in helping to determine whether the produced biodiesel fuel will pass the sodium, potassium, magnesium, and calcium content ASTM test (ASTM EN14538).

Shenandoah Agricultural Products performs this test throughout the biodiesel production process as described in the procedure.

Cloud/Cold Filtration Test

A simple home test that can save time and cover multiple standards is to put a sample of biodiesel in the refrigerator for a few hours. If the sample is cloudy, precipitates are present, or it has become more viscous, then the biodiesel will probably fail one of the ASTM standards. This a valid test because it replicates the temperature reduction and visual inspection that is also in the respective ASTM standard tests.

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Construction and Implementation of a Pyrolysis Unit for the Production of Biochar in a Sustainable Greenhouse Heating System

By:

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Dorottya Spolarics

Julianne Decker

Marlee NajamyWinnick

Advisor: Dr. Wayne Teel

Executive Summary

Biochar is a form of charcoal made using pyrolysis. This process involves the burning of biomass in the absence of oxygen resulting in a carbon rich, high surface area product. The main byproduct of the pyrolysis process is excess heat that is often unused and released into the atmosphere. Our project involves building an efficient pyrolysis unit and capturing the excess heat. This energy is incorporated into an existing system at Avalon Acres Farm in Broadway, Virginia as a backup method for heating a greenhouse. Their current heating system is powered by solar thermal collectors, which are ineffective during cloudy periods in winter. The overall effect of integrating the two units is a sustainable system. We are currently in Phase I of our project involving the construction of the system. The basic construction of the pyrolysis unit is complete; however the plumbing installation is still underway. Phase II will involve producing and characterizing different forms of biochar from agricultural waste. Types of waste include animal manure, crop residue, and forestry prunings. Our project is likely to lead to future projects within ISAT or engineering. On a local level, Avalon Acres will reap the majority of the benefits from this project. These benefits include increased soil quality, crop yields and animal health, all of which can be repeated regionally and nationally. At the national scale biochar could prove beneficial to curbing global climate change by improving soil quality, sequestering carbon and providing an alternative energy source. Currently funding must come from the interested parties who wish to build new biochar systems. As the biochar field expands beyond the research phase, an industry will develop yielding more funding possibilities.

Biochar and Pyrolysis: Explaining the Basics

Biochar is charcoal that is made from organic material through the process of pyrolysis, which burns it in the absence of oxygen. This process produces a friable, black solid with similar characteristics to ordinary wood charcoal, though generally less dense and a higher surface area. Biochar has multiple benefits including carbon sequestration and the improvement of soil quality. The production of biochar is still in its research stage, but it is becoming recognized as further research and implementation of systems continue to reach the scientific world (Taylor 2010).

Biochar can be produced from any type of biomass, but is often made from agricultural waste, yard waste, forestry waste, or animal manure. It is an important concept that biochar should be made only from waste material rather than a potentially usable product. Biochar can be tested and monitored to develop characteristics for optimal use in the soil. Since pyrolysis can affect the nutrient content, each process is different and will not always yield the same results.

Our Project

Our group is composed of four senior Integrated Science and Technology (ISAT) majors at James Madison University led by Dr. Wayne Teel. The goal of our project is to construct and test a pyrolysis unit at Avalon Acres Farm in Broadway, Virginia. The design of the pyrolysis chamber is based on a previous system that had been built on Dr. Teel's property incorporating design improvements. What makes this project unique is that it will be implemented as part of a sustainable greenhouse heating system. Currently, Avalon Acres Farm is heating their greenhouse using solar thermal panels on their rooftop. The energy produced is not a constant source of heat, especially on cloudy or shorter days. In order to provide a solution to this problem, the pyrolysis system constructed will aid in heating the greenhouse when the solar panels are not providing the necessary energy.

The energy produced by the burning of biochar will heat a water tank on top of the unit. The temperature of this water will be monitored by a differential controller. When the water in the pyrolysis tank is hotter than the water in the solar panel systems storage tank, a pump will turn on that will bring the pyrolysis water to the existing tank located in the basement of the residence. The water from the pyrolysis system will be pumped through copper pipes located inside the existing tank. This system acts as a heat exchanger – transferring heat from the pyrolysis tank to the water in the existing tank by conduction through the copper pipes. The water in the solar tank will then be pumped through pipes in the floor of the greenhouse in order to heat it.

Current Status

Phase I of our project includes planning and building the pyrolysis system. Since the start of construction in May 2011, a number of tasks have been completed. The foundation was laid by digging a rectangular hole in the soil and filling it with four to six inches of leveled gravel. Cement blocks were laid on top of the gravel in such a way that allowed air to flow through the floor inside the chamber to feed the fire when burning was in progress (see Figure 2). The frame, designed and welded by Morgan Hager, an Engineering major at James Madison University, was assembled on top of the cement blocks (see Figure 3). The floor of the system was dry laid with fire brick, and three of the walls were constructed with mortar. The mortaring of the brick is an improvement from the previous system on Dr. Teel's farm. The bricks in his system were dry laid, which let out too much smoke during the burning process. The mortaring of the bricks is an attempt to limit this leakage of smoke. Excel Steel, located in Harrisonburg, VA welded a chimney attachment that fits into the back of the system. The door of the chamber is assembled and any exposed holes in the system were filled with rock wool, a high temperature insulator, to prevent further leakage of smoke. The supplies needed for the rest of the construction have been purchased.

Next Steps

The remainder of Phase I involves finishing the construction of the pyrolysis structure. Once the inside of the unit is properly insulated and the inner chamber in place, the water tank will be put on top of the system. Construction of the chimney will follow. The end of the chimney must be ten feet away from the house. This will involve chimney support since the piping is not strong enough to stand on its own. Therefore, this step will involve not only assembly of the chimney, but also construction of the chimney support system. This support system must be sturdy and withstand variations in weather.

After the chimney is complete, the outdoor pyrolysis unit must be hooked up to the farm's existing solar greenhouse heating system. This will likely take the longest to complete since intricate plumbing is required. This part of Phase I involves constructing a plumbing tree that connects the pyrolysis water tank to the existing hot water tank in the basement of the house. This plumbing tree will have valves that drain the outdoor water tank by gravity. This is necessary to avoid freezing in the winter months when the system is not in use. Phase I will end with the completion of the plumbing.

Phase II of the project involves testing the constructed system for efficiency and heat transfer capabilities. It also involves using the system to make biochar. The differential controller used within the system measures the temperature in both the outdoor water tank and existing hot water tank. This will be useful temperature data to help test the efficiency. An average pyrolysis tank temperature can be compared to the existing tank temperature to determine when it is optimal to run the system. An in-line flow meter will determine the flow rate of the system to further test the heat transfer efficiency.

The second aspect of Phase II involves the biochar itself. Many different unique forms of organic waste found on the farm and elsewhere will be used to make biochar. Examples of waste material include animal manure and forest prunings. This biochar will be used around the farm and in the greenhouse. There are many potential uses of this biochar, including feeding it to the chickens on the farm, adding it to the compost pile and amending the soil directly. If time permits, different forms of biochar will be tested in the lab and field to determine the forms that are the most beneficial. Phase II is an ongoing process that will likely end with the conclusion of the academic year.

At the completion of this project, we will have a functional and sustainable biochar greenhouse heating system. What makes this dual-action system sustainable is that in addition to creating biochar, the excess heat from the pyrolysis process will be captured in the water tank and used to heat the greenhouse located at Avalon farm.

Recommendations for Further Research

There is potential for further research beyond the scope of our project. The efficiency data collected can be further analyzed and used to improve the system. Another potential for the future is building the same setup on other farms in the area. Three other farms in the region, Polyface Farm, Wildside Farm and Hermitage Hill Farm, have expressed interest in systems such as ours on their property. Each farm has specific ideas for variations on the system. The building and testing of these systems could likely become ISAT senior projects. Some of these farms could even implement a larger-scale system that will expand the research potential. Overall, our project provides a foundation for numerous projects and there are endless variations and possibilities.

Local, State and Federal Contributions

By designing a sustainable way to produce biochar, this project can provide several benefits to the local, state and national community. Avalon Acres Farm will reap the majority of the immediate benefits. The biochar created by the system is not only important for improving these small-scale farmer's crop health and yield, but is also applicable to their animals. Since biochar is very similar to activated charcoal, it can be used internally to help counteract poisons and toxins in both humans and animals. According to *Baker's Biochar*, when biochar is incorporated into animal feed at rates of 1-2 percent, it can have several positive effects. First, it improves initial growth rate of animals, especially chickens, due to increased feed digestion. Since biochar is known to reduce toxins within an animal's system, a noticeable reduction in diseases has been observed. Manure from animals that have been fed the biochar is often drier, creating easier maintenance of bedding as well as less moisture for bacteria to reproduce. Biochar also ties up free ammonia nitrogen as ammonium ion, reducing odor and preventing leaching losses (Schupska 2011). The biochar also helps to maintain a healthy gut within the animals, thus improving their pH levels. With the increased health of these animals, noticeably stronger reproductive cycles have lead to healthier offspring. Lastly, since biochar helps improve digestion, there is less gas produced within the gut of the animal resulting in less greenhouse gas emissions (*Baker's Biochar)*. Thus, Avalon Acres can incorporate the biochar within their animals' feed as well as their soils. Small-scale as well as large-scale farms within the surrounding areas could all benefit from such technology, especially since Rockingham County is highly populated with poultry, dairy, and beef farms.

On the state level, biochar can serve to fertilize soil, and curb climate change as seen in Wardensville, West Virginia. This particular poultry farm removes the chicken waste from its houses and places it into an experimental pyrolysis unit. The biochar produced helps keep the carbon in the soil instead of letting it escape into the atmosphere, where it acts as a greenhouse gas. The process involves heating the manure in an extremely low-oxygen environment, thus producing little smoke and smell resulting in significant environmental benefits. Instead of the natural release of carbon that comes from the matter decaying, biochar is resistant to this conversion. In some cases, it can "lock" the carbon into the soil for up to a millennia (Taylor 2010). This process removes carbon from the atmosphere. This can be seen in Figure 1 below.

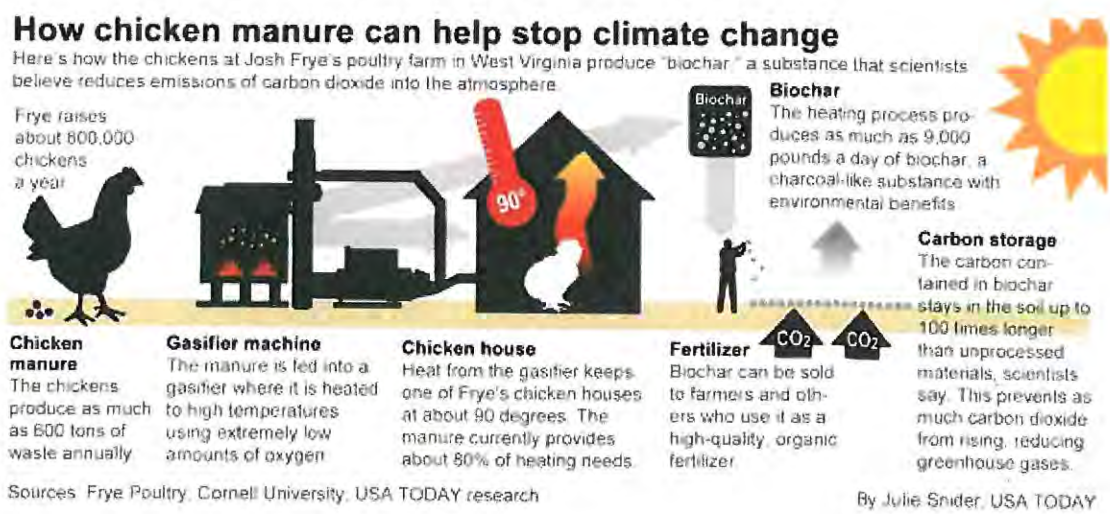

Figure 1. Diagram illustrates the benefits yielded from using chicken waste as a form of biochar.

Therefore, even small-scale efforts could make a significant impact on emissions on a global scale. This process has great potential for large-scale producers as well, including dairy farms and chicken house operations around the state of Virginia. A profit may also be provided to those farmers who become involved. In the case of the Wardensville chicken house, they pyrolyze as much as 9,000 pounds of biochar a day and are able to sell it for approximately $1 per pound (Winter, 2010). By implementing this technology on both a local and state level, we could potentially clean up the air, reduce greenhouse emissions, increase livestock health and longevity, remediate soils, and increase crop yields. There is much potential and the desire for access to this up and coming green technology is building rapidly.

At this point, the scope of our project is limited to the local area supplementing small scale agriculture. However, it has the potential to be applied on a larger scale with the right funding and resources. All aspects of the biochar making process could prove beneficial at the national level. It is a natural way to improve soil quality, meaning that fertilizer use could decrease when biochar use increases. Biochar integration improves the nutrient holding capacity of the soil – meaning the soil would retain the nutrients it already has. This permits fertilizer reduction or elimination, and the associated negative side effects and impacts on the environment will be reduced as well.

Making biochar is a great way to handle agricultural waste, and could be done on a large scale to process manures and plant material. The carbon in these agricultural waste products would be sequestered, reducing our ecological footprint. While the carbon released by small scale agricultural waste may not seem like a lot, the total waste from all United States farms (big and small) is significant and sequestering this carbon could help reduce carbon dioxide in the atmosphere.

The greenhouse heating aspect of our project could also be applied on a large scale as a sustainable energy source. The pyrolysis process generates large amounts of excess heat, most of which is usually released to the environment. However, this heat can be captured in systems like ours and used as a heat source for small buildings or greenhouses. Although it may not be practical to use this excess heat as a source of electricity, using it to heat small buildings is viable and efficient. Pyrolysis systems could potentially be integrated into greenhouse systems across the country, reducing the need for other forms of space heating using fossil fuels.

Potential Funding Sources

If a pyrolysis system is to be built on a farm, it is likely that the owners of that farm will fund the construction process. At this stage in the awareness and education about biochar, it is not likely that there will be ample funding sources. Therefore, it will be the responsibility of the farmer to fund his/her pyrolysis unit. Several farms in the Shenandoah Valley area have expressed interest in building a pyrolysis unit and integrating biochar into their farming practices. If biochar proves a profitable soil amendment, the cost of building a pyrolysis system could be covered by increased yields and reduced fertilizer cost.

Eventually, if biochar production is brought to a national level, there is the potential of government subsidies or incentives for pyrolysis units and biochar production facilities. This funding could serve as a stimulant, encouraging farmers to use alternative sources of energy and fertilizers. Government funding for biochar would be nationally beneficial in that it would improve soil quality and increase crop yields.

There is also the potential for a biochar industry in the future. Businesses could start that build pyrolysis units on individual farms. Biochar-production businesses could handle agricultural waste for a small price and sell the biochar to farmers. In these cases, pyrolysis and biochar would be funded by the companies in a marketplace environment.

Appendix

Figure 2: Foundation: involving 4-6 inch rectangular hole with leveled gravel and cinder blocks.

Figure 3: Steel frame and beginning of floor and brick wall

Figure 4: Current status displaying finished floor, wall and attached floor and water tank

Figure 5: Current status displaying alternative view of wall, door and water tank

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Final Report

To

The Institute for Energy and Environmental Research (IEER)

at

James Madison University

and

Valley 25x'25

for

Development and Implementation of an On-Campus GPS Bike Sharing Program

By

Dr. Anthony A. Teate

EXECUTIVE SUMMARY:

The researchers have developed a Prototype GPS Bike-Sharing Program which includes two bicycles (one for male riders and one for female riders), each outfitted with a GPS-enabled phone which transmits its location, one of the bicycles being additionally outfitted with a bicycle-powered generator to help maintain the cell phone battery charge; a database which logs the bicycles' movements and rider usage; and a website which displays the current location of each bicycle and allows students to register and "check out" a bike online.

The bike-location tracking system was effectively installed and is currently being tested by students on campus, and the data points are actively being stored in a database designed specifically for this project. A website was developed using ASP.NET technology which displays the bicycles' current locations and can be viewed by students with access to determine whether the bikes are in use and where they are currently located.

It is recommended that further research be conducted on additional methods of transmitting the bike locations, and that the project be expanded to be utilized by the general student population at James Madison University.

METHOD AND RESULTS:

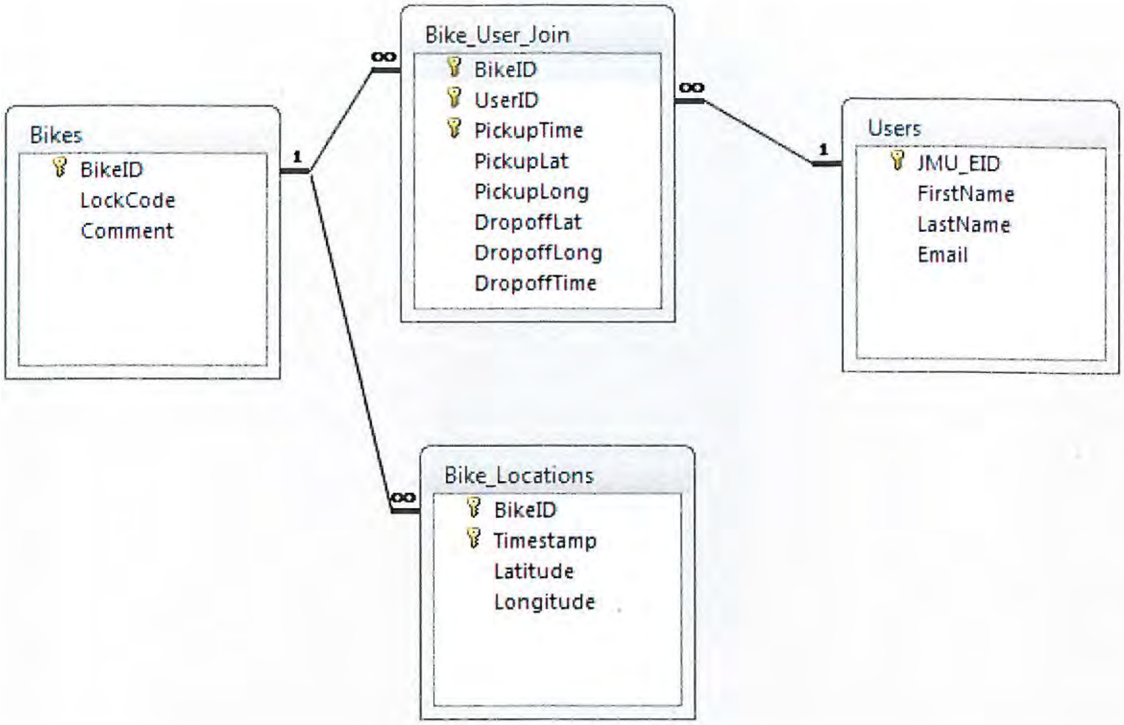
After extensive research to determine the most feasible method for tracking the bikes via GPS without requiring expensive smartphones, data plans, or proprietary kits and web services, it was determined that inexpensive pay-as-you-go phones which utilized the iDEN (Sprint/Boost Mobile) network would be ideal. The phones have GPS transceivers and some minimal web capabilities which meet the project needs, and can be enabled at a cost of only 35 cents per day (less than $11/month) with no long-term contract required.

A Java application called "GPS Tracker" was installed on each phone to allow it to send the phone's current GPS location to a free web service called InstaMapper, which has an API that can be accessed by the project website so the bike locations can be retrieved, stored in our database, and displayed on the project website. Other web services researched required subscription fees or required that visitors to the project website be directed to their websites to view the phone locations, but InstaMapper provided the latitude and longitude of each tracked device as a text stream which could be parsed programmatically, and only required an attribution link on the project website. The phone app which sends location data to InstaMapper is pictured in the simulated image below.

InstaMapper "GPS Tracker" App Running on Motorola i465 Clutch Phone

A VB.NET program was developed that can run on a server, continually retrieve the GPS location data, and store it in a MS Access database designed for this project. It stores the current date, time, and location of each bike every 90 seconds if the bike is not moving, and every 10 seconds (the interval at which the phone app sends location data to InstaMapper) if movement is detected.

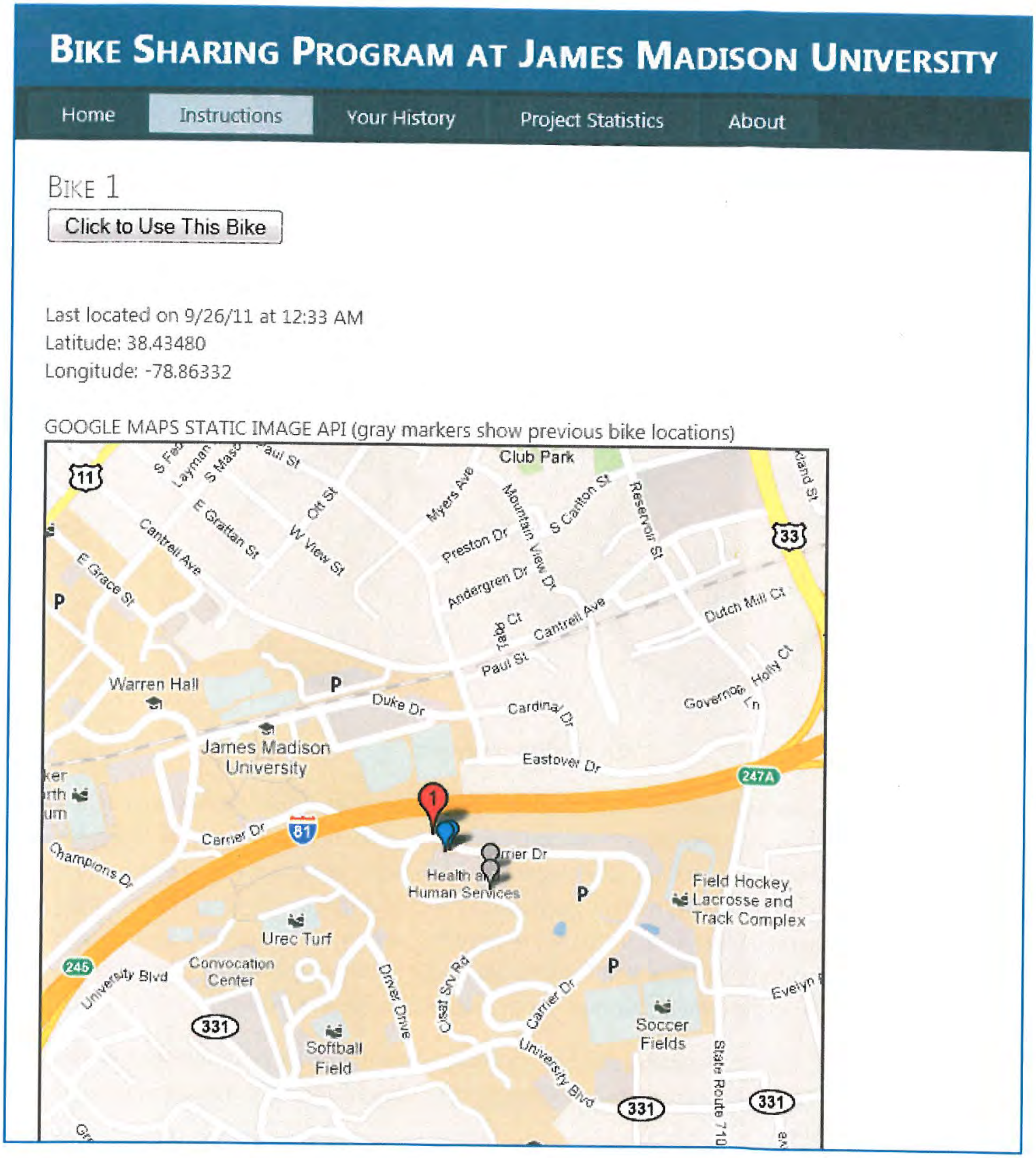
The relational MS Access database stores a record for each registered user, check in and check out times when a user is utilizing a bicycle, and bicycle location data regardless of whether it is currently checked out.



Database Table Relationships

Because the database continually stores the bicycles' locations and check in/check out data, usage statistics can be generated on the amount of time the bikes were in use and approximate distance travelled.

The project website was built using ASP.NET technology and displays data from the database to indicate the current location of each bike and whether or not it is currently in use. The display is user-specific, so when the user that has checked the bike out logs on, they see a check-in button. Also, an optional function can be enabled that will automatically check a bike back in if it has not moved in over 15 minutes, displaying it as available for another person to utilize (since the system is designed so if a student sees a project bike locked to a bike rack, they can log on the website and check it out for immediate use, this would make the bike available if the previous rider forgot to check it back in).



Current Project Website

The website can be viewed in standard computer browsers or on smartphones that can browse the web, and uses standard Google Maps to display the bike locations.

Bicycles were purchased from Shenandoah Bicycle Company in downtown Harrisonburg, VA. The researchers consulted with a bicycle expert to choose two bicycles that were priced within the project budget and would be easily rideable by most students on campus, regardless of experience. It was also important that the bikes be maintainable by the IEEE club during the prototype testing phase of the project. The bicycles purchased were Trek 7000-Series: a 20" male-frame and a 16.5" female-frame to allow riders of various heights to have two sizes to choose from. The bikes have aluminum frames, all-purpose tires, 21-speed twist-shift gears, and a "cruising" upright seating position with seats that can be height-adjusted by hand. The smaller-framed bicycle was outfitted with a pedal-powered generator to help maintain the charge on its locator cell phone.

TREK 7000 Men's Bicycle

Standard combination-lock bike locks were purchased to secure the bikes to bike racks when not in use. Because of time and material limitations, a "lock box" was not developed to securely attach the phones to the bicycle frames. At the current time, only students working with the project are able to utilize the bicycles, and they keep the phones with them, maintain cell phone charge (on the phone not charged by the pedal-powered generator), and hand them off to each other as needed. The phones are protected from weather by being stored in a "Cage Box" waterproof plastic container that fits in the bicycles' water bottle cages and is made from plastic that the GPS signal can transmit through.

The bikes, GPS phones, website, database, and battery-charging generator are currently being tested by IEEE Computer Society students, and results generated will be analyzed and made available by the time of the project presentation.

DELIVERABLES:

- Two bicycles (one for male riders and one for female riders), each outfitted with a GPS-enabled phone which transmits its location

- One of the bicycles is outfitted with a bicycle-powered generator to help maintain the cell phone battery charge
- A database which logs the bicycles' movements and rider usage, and
- A website which displays the current location of each bicycle and allows students to register and "check out" a bike online to receive the bike's unlock code and indicate that they are currently utilizing it so per-rider usage can be tracked

RESEARCH CONTRIBUTIONS

The research conducted during this prototype phase of the project primarily centers around GPS, database, and website functionality, and overall project feasibility.

In the next planned phase of this project (larger-scale implementation accessible to the general student population) will allow for collection of data on bike usage by students not directly involved in the project development, and comparison with other campus bike-sharing projects based on usage statistics and survey feedback.

BENEFITS TO LOCAL/STATE/FEDERAL GOVERNMENT

Implementing a larger-scale bike-sharing program on James Madison University's campus based on this prototype project could encourage bicycle riding by students that don't own their own bicycles and would normally use gas-powered transportation to travel to class. The convenience of being able to pick up any available bicycle without having to reserve it in advance, and being able to drop it off at any campus bike rack, could encourage ridership by students that wouldn't otherwise utilize a bike-sharing system.

Increased bicycle ridership could help the Valley meet its goal to achieve 25% renewable energy in the Shenandoah Valley by the year 2025. It also provides health benefits to riders because of the additional exercise achieved by riding a bicycle instead of walking or taking a bus or car. Additionally, increased bike ridership can help reduce traffic congestion and pollution generated by gas-powered vehicles.

RECOMMENDATIONS FOR FURTHER RESEARCH

It is recommended that additional GPS location and transmission methods be studied. The researchers found that the pay-as-you-go cell phones sometimes have difficulty determining and transmitting a GPS location in a timely manner, and therefore can leave gaps in the path traveled by the rider in the location data log. A smartphone with a more powerful GPS transceiver that can also utilize both cell phone network data transmission as well as wi-fi data transmission when in range of the JMU wireless network would be ideal. That way, both cellular and wi-fi transmission options will be available, and the GPS tracking data would give a more complete view of distance travelled. However, a modern full-capability smartphone would likely use up the battery charge more quickly and would also be more vulnerable to theft.

Additionally, the current bike-sharing system should be scaled up to include more bicycles that are made available to all JMU students, therefore generating usage data in a real-world setting and gaining information about this system's acceptance by students, allowing for comparisons to other bike-sharing systems on campus.

CONCLUSIONS

We consider the prototype GPS-enabled bike sharing units to be successful in their design and specifications. We also received enthusiastic support from students that wanted to participate in the testing phase of the system. This was an early indicator that the concept would be successful in the implementation phase, as it is proving to be.

Valley 25x'25/JMU IEER Project Final Report

Project Title: *Educating and Engaging Local Organizations, Community Members, and University Students thru an Energy Efficiency and Sustainable Buildings Community Outreach Program*
"Green Impact Campaign"

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Executive Summary

The Valley 25x'25 funded project, *"Educating and Engaging Local Organizations, Community Members, and University Students thru an Energy Efficiency and Sustainable Buildings Community Outreach Program"* has developed a fully operational community outreach project that is currently being implemented in the Shenandoah Valley and other communities. The project, Green Impact Campaign, connects students with local businesses as a way to recognize tangible energy efficiency opportunities within organizations through public recognition and free energy services.

Green Impact Campaign (www.greenimpactcampaign.com) is an innovative training program that allows students to perform energy audits for local businesses in their community. The program is centered around a web-based platform that requires no previous energy auditing knowledge and allows students to complete a full energy audit in less than one hour, all while receiving energy audit experience. The web-based, mobile accessible program, GEMS (gems.greenimpactcentral.com), is a self-training energy audit tool that guides student volunteers through a facility identifying lighting, plug load, HVAC, building envelope and water energy conservation measures (ECMs). Based on user input, GEMS then references a catalog of ECMs, calculates energy saving estimates and compiles a report that is then sent to the participating business. Through this process, local businesses receive free energy efficiency advice, students gain real world hands on green job experience, and both are working to make a positive impact on the planet.

For any organization or business that is interested in having a free energy audit performed, they are required to take a sustainability oath called the Green Impact Pledge. The pledge is an online, public oath that confirms that the organization is interested in reducing its environmental impact and they plan to take action in implementing changes. Any organization who takes the Pledge is then promoted to the community as an active organization who is concerned with environmental sustainability.

Net Impact has entered into a partnership with Green Impact Campaign to offer the project as a sponsored project to its network of student chapters. As of this report's creation, twenty student Net Impact chapters have agreed to implement Green Impact Campaign in their community. Twelve businesses have taken the Green Impact Pledge and four have received energy audits. In total, 22,258 kWh of energy reductions have been discovered during the energy audits. Green Impact Campaign won the 2011 Force for Change Award for its positive environmental and social impact through its use of grassroots efforts.

In the future, the project will be improved and further developed in several ways. First, the follow up process for businesses that have received energy audits will be more comprehensive. Second, further refinements to the GEMS program will be made to improve the accuracy of estimates and additional unit conversions. Third, GEMS' project management features will be further expand by adding a service provider directory and an ECM/utility tracker. Fourth, additional audit topics will be replicated using the GEMS energy audit methodology.

Products/Deliverables

Upon completion of this research grant, the following products, deliverables, and/or contributions have been completed:

- 'Green Impact Campaign' Methodology
- Sustainability Pledge
- Energy Survey Methodology
- ECM Catalog
- Energy Survey Sheet
- GEMS/GEMS Mobile
- Net Impact/Green Impact Campaign Introductory Guide
- Net Impact/Green Impact Campaign Energy Survey Express Guide
- Net Impact/Green Impact Campaign Promotional Video
- Green Impact Campaign Website

Each of the above products/deliverables/contributions are explained or included below.

'Green Impact Campaign' Methodology

Our development of a community outreach program focused on two primary components: a public sustainability commitment and free energy and sustainability consulting services. Each of these components has its own benefits and purposes that help to strengthen the other component.

Based on research done in the community based social marketing field, public commitment is a powerful tool when dealing with behavioral or habit changes. It is believed, that if a person or organization makes a small commitment, such as taking an oath, they are more likely to both follow that commitment and agree to a larger commitment at a later time. The reasoning is that people value consistency in the eye of the public. Following this same logic, our approach to beginning energy efficiency education, awareness and action in the community would start with a Sustainability Pledge. Organizations would take the Pledge to make an oath to the community to make an effort to practice green business practices. In this way, we hope that this small, initial commitment would lead to the organization following through when the opportunity presents itself to make a larger commitment, such as implementing real changes.

The other component of the outreach methodology is free energy and sustainability consulting services, specifically energy and sustainability audits. Every organization that takes the Sustainability Pledge would receive an energy audit as a way to show them the various opportunities available to their organization. This free service would identify low cost and zero cost opportunities that could directly have an impact on their energy consumption and carbon footprint. The combination of these two components would give an organization enough information and public recognition to make real changes within their organization. The ultimate goal of this outreach program would be for the organization to become more energy efficient, environmentally aware, and sustainable.

The final component of this outreach program is the heavy involvement of students. The program would be packaged in a way that student volunteers run the project and perform the energy audits. This would include students identifying organizations and engaging them to participate as well as following up with previous participants.

The Green Impact Campaign project has three publicly promoted goals. First, to make a positive impact on the community and the planet. Second, to help small businesses gain access to resources that will allow them to join the green movement. Third, to provide students with real world hands on experience in the green industry that can be used in future careers.

Sustainability Pledge

The Sustainability Pledge, which was named, The Green Impact Pledge, combines the objectives and goals of Valley 25x'25 with general sustainability pledges used within private organizations such as Google and Harvard. The pledge has three major components. The pledge starts with a statement on social responsibility to show the relative scale of such a promise on not only the community level, but the planet as well. Next, the pledge states the importance of taking action and what it means to be sustainable. Last, the pledge talks of not only joining the green movement but also serving as a responsible leader in showing the community the importance of being green. It is this fully encompassing style that we believe makes this pledge more than a generic statement.

The pledge is as follows:

The Green Impact Pledge

"Our organization pledges to take action to uphold our social responsibility to the community, the environment, and the planet. We promise to take steps towards reducing our carbon footprint, reducing wasteful practices, preserving natural resources and ensuring an ethical guarantee behind all business we do within the community. We will make a commitment to be a steward of the environment and be accountable for our effect on the planet. We will join the campaign of green organizations that are working towards a healthier, more efficient tomorrow by helping to raise awareness, promote sustainable business, and encourage customers to be more green conscious."

Organizations can take the pledge by accessing it on the Campaign website and filling in the appropriate information. The website will be discussed later on in this report.

Streamlined Energy Survey Methodology

Based on the community outreach methodology, any organization that takes the Green Impact Pledge is offered a free energy survey. Traditionally, energy audits or energy surveys are a timely process. We sought out to develop a more streamlined approach that integrates technology and student volunteers. For future use, the term ECM refers to an energy conservation measure. This can be in the form of a device, technology, or behavior.

Our research team started initial discovery by examining traditional energy audits, looking at the process and the final report. We looked at two specific audits that were conducted for a restaurant, Dave's Downtown Taverna, and an apartment complex leasing office, St John Wood's. Our primary interest in this research was to observe what steps in the energy audit process consumed the most time and identify ways of automating any steps in the process. From our investigation, we determined that the average, traditional energy audit process for these two cases consisted of five primary steps:

1. Site survey (1 day/3 hours) – Physical walk through of a facility to identify what energy systems are currently present.
2. ECM Discovery (2 days/12 hours) – Review of the site survey findings and identification of potential ECM recommendations.
3. ECM Calculations (4 days/20 hours) – Performing research on potential ECMs and calculating potential savings compared to the baseline of current energy use.

4. Report Narrative (5 days/32 hours) – Writing of ECM descriptions and current state of facility systems, including specific recommendations.
5. Package and Delivery (1 day/4 hours) – Compilation of all information for recommendation into a final report that is sent to the recipient.

The average time for the two investigated audits was 13 days or 71 work hours, which includes Site Survey to Package and Delivery.

We set out to develop a methodology that would drastically cut down the audit time. We determined several key ways that this could be accomplished and made some additional assumptions.

- The Site Survey step was necessary since it required human observation and physical cooperation.
- If we focused on low-cost, no-cost ECMs, we could create a preset number of best practice ECMs that would be looked for in each general business facility.
- If we then had a preset list of ECMs that were to be looked for, the Site Survey could be standardized based on this list by using a checklist system that combines the Site Survey step with the ECM Discovery step.
- If we know what specific ECMs are being considered, we could prepare narrative and formulas for each ECM possibility as a way to automate ECM Savings Calculations and Report Narrative writing.
- If general assumptions about energy systems are made, we can provide a process that gives quantitative savings estimates that can be used to prioritize changes.

From these points, we determined our methodology would use a streamlined workflow with the influence of web based technology integration:

1. Site Survey using standardized ECM checklist – Physical walk through of the facility using a checklist that focuses on a fixed list of best practice ECMs for general business facilities. In this way, the Site Survey and ECM Discovery would be completed simultaneously since the survey would be guided by specific ECM possibilities.
2. ECM Catalog and Formulas – Based on the results of the Survey checklist, a list of ECM recommendations would automatically be compiled. These recommendations would reference a premade catalog of factsheets for the ECMs along with prefixed savings estimate formulas for each ECM.
3. Package and delivery – The packaging of these materials and calculations could all be done by a web-based program that contains the ECM database, ECM formula algorithms, report templates and an automated email system that sends the resulting report to the organization.

With this streamlined approach, we can complete an energy audit with limited ECM potentials (which we'll call an energy survey) that still conveys the necessary information to make an informed decision. The only physical step in the streamlined process is the Site Survey which would take less than one day. But, with a limited list of observations to be made during the survey, we can estimate that the typical three hour site survey could be done in one hour or less. The remainder of the process would then be completed by a web-based program, meaning the entire process could be completed in one hour or less. This streamlined process would reduce the time it takes to complete a traditional energy audit by 72 working hours, keeping in mind it's focus on only low-cost and no-cost ECMs and its limiting accuracy of savings estimates.

ECM Catalog

Research began with investigating and compiling a list of best practice energy conservation measures (ECMs) most commonly present in a facility used for general business. Since the focus of this information was small businesses and nonprofits, the emphasis of research was done on ECM retrofits and recommendations that were primarily low-cost or no-cost to implement. The research team consisted of Daniel Hill and the assistance of four undergraduate JMU students. The research team consisted of the following:

Researcher	Major/Year
Daniel Hill	MBA 2011
Corey Allison	Engineering 2014
Derek Zuk	ISAT-Energy 2011
Donny Jagoda	ISAT 2013
Gareth Hermann	ISAT 2012

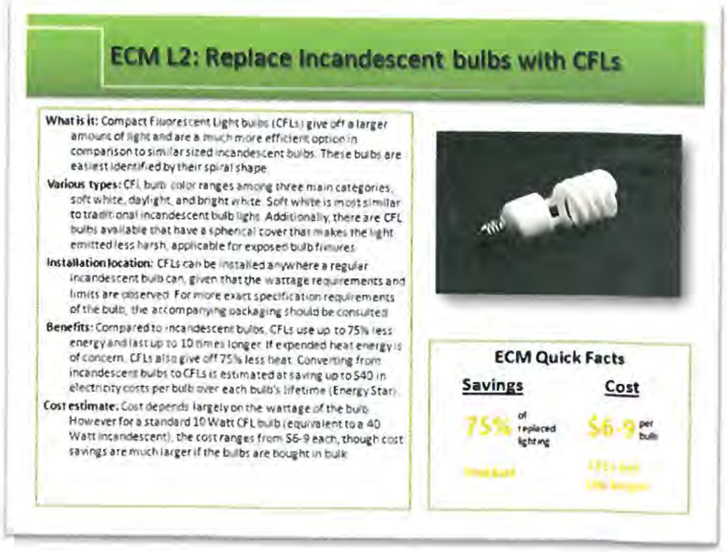
Sources of information were gathered by a combination of industry evidence and industry knowledge sources such as Energy Star, Department of Energy, and United States Green Building Council. In total, the team researched the following 31 ECMs:

- Lighting
  - Delamp unnecessary bulbs
  - Replace incandescent bulbs with CFLs
  - Install occupancy sensors
  - Optimize task lights
  - Install LED exit signs
  - Upgrade T12 bulbs to T8 or T5
  - Utilize daylight harvesting tools
  - Install dimmer switches
  - Label light switch panels
  - Install photocell sensors
- Plug Load
  - Utilize power strips
  - Purchase Energy Star equipment
  - Set sleep timers and power options
  - Unplug unused equipment
  - Replace inefficient vending machines
- Building Envelope
  - Weather strip doors
  - Increase wall insulation
  - Increase roof insulation
  - Caulk windows and cracks
  - Replace inefficient windows
- HVAC
  - Install programmable thermostat
  - Correct the date and/or time on thermostats
  - Replace furnace filter
  - Retro-commission HVAC systems
- Water
  - Downsize hot water heater
  - Install aerators on faucets
  - Install aerators on shower heads

- Install low flow toilets
- Install a rain barrel for outdoor watering

- Alternative Energy
  - Install PV panels
  - Install solar hot water

For each ECM, an ECM Factsheet was created that would convey general information that would educated the general audience about key points. These factsheets each answer a certain amount of questions including: What is the ECM, What are the various types, When is it used, Where is it installed, What are the benefits of the ECM, What are the costs for the ECM, an example image and "Quick facts" to convey cost estimates. These questions were considered the most important knowledge by the research team after reviewing several comprehensive energy audit reports. An example of one of the factsheets can be seen below:



In addition to energy and water conservation measures, we conducted research and compiled factsheets on recycling best practices and organizational greening. Organizational greening is the conservation strategy of using human behavior to drive environmental and energy sustainability. The complete ECM Catalog, consisting of factsheets for each ECM researched, can be found attached to this report and as a separate attachment.

GIC ECM Catalog.pptx

Site Survey Sheet

After the ECM Catalog was compiled, we developed a Site Survey Sheet that would integrate with the catalog. The purpose of the sheet was to lead the person conducting the energy survey through the facility using guided questions that would be used to make observations in order to identify specific ECM opportunities present in the facility. With consideration that student volunteers will primarily be using this process, we focused on making the sheet self-training. Self-training is used in this regard as a student being able to use the Site Survey Sheet without having any prior knowledge or training in energy audits or green building features. The sheet was designed with the focus that it provides enough information that the student can successfully complete the survey as well as gain knowledge in green building features while conducting a survey.

The sheet was designed to use a checklist system with Yes/No/NA questions. Each question would prompt a specific observation to be made within the facility, based on the limited number of ECMs in the ECM Catalog. For every question, there is a self-training description that informs the volunteer of all the information they need to know about the question in order to successfully answer the question accurately. Each question in the checklist would contain three components:

1. *Question*: The specific observation to be made in the facility in Yes/No form.
2. *Description*: More detailed information on what is being asked in the question.
3. *Image*: When applicable, a picture of the device or system in question.
4. *ECM Code*: Based on the response of the question, a specific ECM would be recommended from the ECM Catalog.

This sheet would then integrate with the ECM Catalog in order to automatically compile a list of ECM recommendations for the organization. In this way, we have combined the ECM discovery step with the site survey step of an energy audit. The completed Site Survey Sheet can be found attached to this report and as a separate attachment.

Energy Survey Sheet.pdf

Green Energy Management System (GEMS)

David Hussey was the project leader for the development and integration of materials into a web based platform. The web-based program, that contained the above information and materials, was given the name GEMS. GEMS has two primary components to it, one is a mobile based web application that is used to conduct the Site Survey, the other is a web-based program that contains the ECM catalog, preset formulas, report compilation and delivery code. The GEMS program can be accessed through the web by going to gems.greenimpactcentral.com on a computer or a smartphone (GEMS Mobile).

GEMS Mobile is accessible by using a web-access phone or mobile device. When accessed, the student is prompted to enter in a reference code. This reference code corresponds to the organization or business that is having the survey completed. This code connects any inputted information directly into the web account of that business which allows GEMS to construct a report specific for their organization and allows the information that is inputted to stay organized. Additionally, the reference code has the contact information such as email address stored which allows GEMS to automatically send the correct report to the correct contact address once the survey is completed. After entering in the reference code, the student volunteer begins by selecting one of five systems. Once selected, a series of survey questions will appear on the screen. An example screenshot is shown below:

Screenshot of GEMS Mobile

The questions in GEMS Mobile are the same as those previously described in the Energy Survey Sheet that was created. GEMS Mobile allows the student to interact with the question in order to discover more information for each question such as descriptions and images. After the volunteer understands what is being asked, he/she marks Yes, No or N/A and inputs the appropriate quantity (for example, number of incandescent bulbs in use) and moves on to the next question. Once all questions for a system has been answered, the volunteer clicks save and those results are then stored in the program according to the reference code. The survey is completed once all questions for all systems have been answered and saved.

Once a student volunteer uses GEMS Mobile to conduct the Site Survey, the program automatically does the following steps:

- Compiles the list of recommended ECM Factsheets based on the user input.
- Performs calculations based on user input quantities to provide estimates for energy and cost savings for each ECM recommended. If a question does not ask for an input, GEMS uses a flat rate savings percentage that is dependent on information too detailed to gather during the survey observations.
- Performs environmental equivalent calculations based on the energy savings.
- Compiles all of the above information into a single report template, along with filling in information such as the date, organization name, etc.
- Sends a notification email to the organization's contact that the report is ready to be viewed and a link to the report.

A sample of the report that GEMS produces following the completion of a survey can be found in the appendix of this report. The following document shows a detailed tutorial of how GEMS works and how it is used by a student volunteer. The tutorial also shows what the business receives in terms of email notifications and survey reports.

GEMS Tutorial.pdf

Net Impact/Green Impact Campaign Resources

After establishing a partnership with the international nonprofit organization Net Impact, we entered into an agreement to provide resources and materials for Net Impact to distribute to their student chapters in order for Net Impact to offer the Green Impact Campaign project as a sponsored project. These resources would be used to get students acquainted with the project and get them interested in participating.

Net Impact/Green Impact Campaign Introductory Guide

The Introductory Guide was developed for student Net Impact chapter clubs that would be implementing Green Impact Campaign in their community. This Introductory Guide explains the goals of the project, how it works, how to successfully run the project, how to get businesses participating and how to use GEMS.

GIC_IntroductionGuide_v9.docx

Net Impact/Green Impact Campaign Energy Survey Express Guide

The Energy Survey Express Guide was developed as a quick reference for student volunteers to use when conducting an energy survey for a business using GEMS Mobile. The guide provides step by step instructions and screenshots for students to understand the process without previous training or knowledge.

GIC Survey Guide Express.docx

Net Impact/Green Impact Campaign Promotional Video

In addition to the text based guides, we used marketing funds to create a promotional video that could be used for both students and businesses. The video was created to show the tangible components of the project and how the process works as it actually happens. Also, the video strengthens the goals of why this project was created.

Each video can be seen at the following links:
Net Impact students: http://vimeo.com/26769819
Businesses: http://vimeo.com/26770390

Green Impact Campaign Website

Green Impact Campaign's website is located at www.greenimpactcampaign.com where the following information can be found:

- About page describing the outreach project and its components.
- Pledge page that contains the Green Impact Pledge and a submittal form for organizations to take the pledge.
- Pledges page that displays all organizations who have taken the Green Impact Pledge.
- Net Impact Chapters page that displays all Net Impact school chapters that are participating in the Green Impact Campaign project in their community.

- Partners page that displays all participating organizations that are supporting Green Impact Campaign.
- FAQ page that answers commonly asked questions in regards to the Campaign.

David Hussey was the designer and developer of this site and did the integration between the GEMS program and the Green Impact Campaign website. This Wordpress website integrates with the GEMS Drupal website in order to communicate information regarding Pledges contact and register information. When an organization takes the Pledge on the Green Impact Campaign website, an account is automatically created for them at the GEMS site and a reference number is created which is then used when conducting the energy survey. This unique reference number is what creates a report that only that organization has access to view.

In addition to the website, a Facebook page for Green Impact Campaign was created in order to keep the Facebook community updated with businesses that Pledge and universities that are participating in the project. Additionally, the page was created to foster collaboration amongst participating schools. The page can be found at http://www.facebook.com/pages/greenimpactcampaign and as of September 28, 2011, the page has 153 fans.

Results

As of September 29, 2011 the Green Impact Campaign has achieved the following results.

Net Impact Partnership

In June 2011, we entered into a partnership with the global nonprofit organization Net Impact. The partnership was a project based relationship in which both parties would work together to promote, implement and maintain Green Impact Campaign as a Net Impact project during the 2011-2012 school year. The MOU can be found below that outlines each party's responsibilities.

MOU_Green Impact_v2.docx

The partnership's primary purpose was to tap into the preexisting student club chapters of Net Impact across the country and engage these chapters in implementing this project in their community. We worked together to develop guides and materials that would allow students to manage this project in their community without assistance from our team. The project was promoted as a "Project-in-a-Box" that students could quickly begin working on. The following blurb is an example of one of the notifications sent out to the network of Net Impact student chapters:

> **Project-in-a-Box – Perform Energy Audits and Learn Green Business**
>
> **Learn** about green business and energy surveys, **build career skills, gain experiences to add to your resume** and, **enhance your community** by helping businesses reduce their environmental impact.

Sign up for the Green Impact Campaign to receive an easily manageable, self-training toolkit for individuals to perform free one-hour energy audits for small businesses. No previous knowledge of energy audits necessary, just a desire to learn and make a positive, measurable impact.

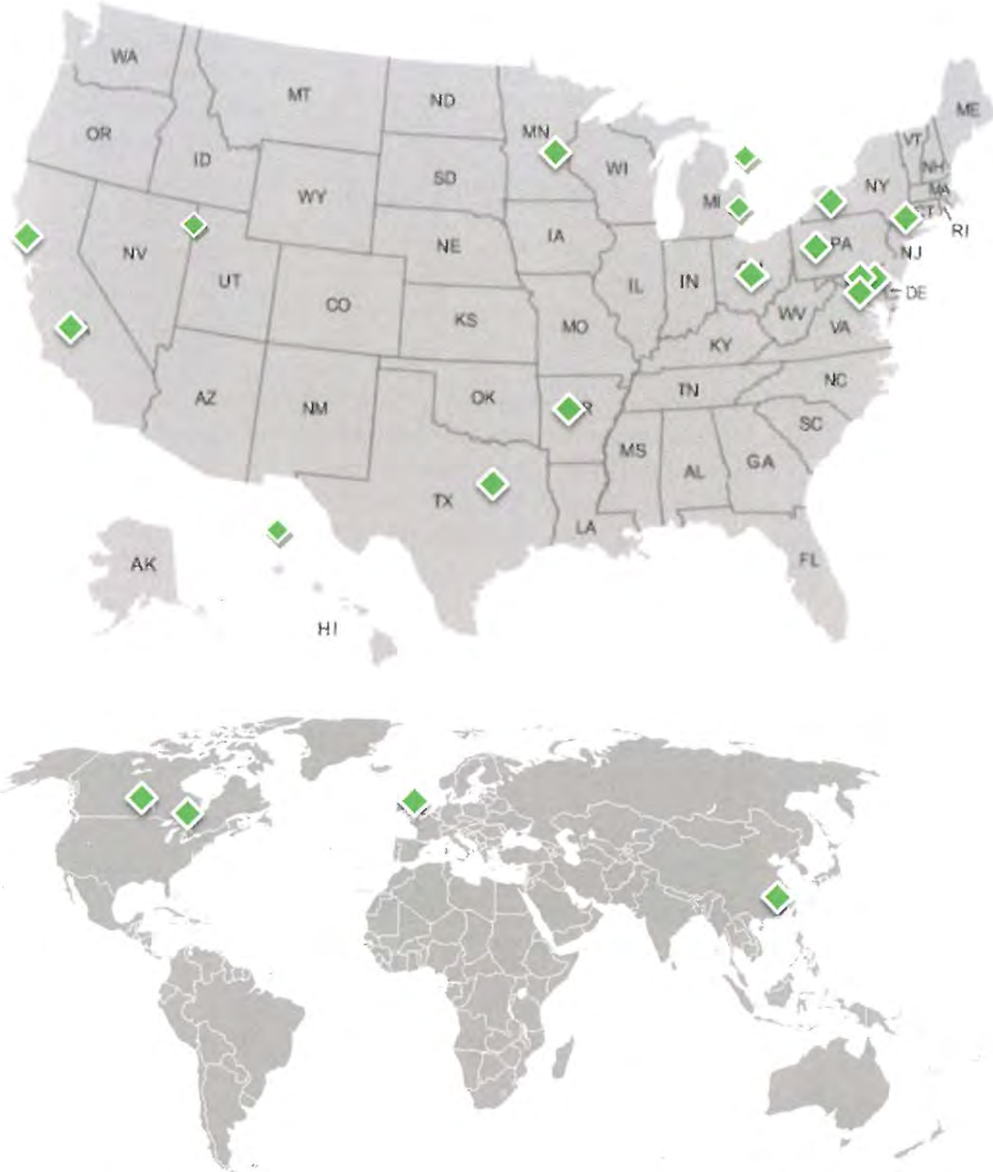
Additionally, Net Impact has a subpage dedicated to the Green Impact Campaign project that allows students to learn more about the project and steps to implement the project in their community. The subpage can be found on Net Impact's site at http://www.netimpact.org/displaycommon.cfm?an=1&subarticlenbr=631.

Twenty Participating Net Impact Chapters

As of September 29, 2011, twenty Net Impact student chapters have signed up to implement the Green Impact Campaign project in their community. The following is a listing of the participating schools:

- James Madison University
- New York University - Stern School of Business - Graduate
- Carnegie Mellon University - Tepper School of Business - Graduate
- University of Arkansas at Little Rock - Graduate
- University of Rochester - Simon Graduate School of Business - Graduate
- University of Maryland - R.H. Smith School of Business - Undergraduate
- University of St. Thomas - Opus College of Business - Graduate
- The George Washington University - Graduate
- Texas State University - McCoy College of Business Administration
- University of Exeter - Undergraduate
- The Ohio State University
- Monterey Institute of International Studies
- Queens University - School of Business - Graduate
- University of San Francisco - Graduate
- University of Alberta School of Business
- Tsinghua University
- American University
- Penn State University – Smeal School of Business
- British Columbia Institute of Technology
- Claremont Graduate University

Fifteen of the participating chapters are located within the continental United States and an additional five chapters are located abroad. Of those international chapters, three are located in Canada, one in United Kingdom, and one in China. The following map represents the geographical locations of each participating chapter.



Map showing participating Green Impact Campaign student Net Impact chapters.

Twelve Business Pledges

The term Pledges is used for any business or organization that has taken the Green Impact Pledge. Pledges are not required to receive an energy survey. As of September 27, 2011, twelve organizations have taken the Green Impact Pledge. A complete listing of the "Pledges" can be found at http://www.greenimpactcentral.com/pledges/.

Business/Organization	Industry/Type	Location
The Green Corner Store	Eco-store	Little Rock, Arkansas
Gal Gone Green	Cleaning services	Broadway, Virginia

Immerge Technologies	Web services	Harrisonburg, Virginia
Shenandoah Valley SBDC	Consulting	Harrisonburg, Virginia
OASIS Fine Art and Craft	Art gallery	Harrisonburg, Virginia
20 Minute Resume	Consulting	Staunton, Virginia
Natural Design Concepts	Landscaping	Earlysviller, Virginia
The Gaines Group	Architecture/Design	Harrisonburg, Virginia
Friendly City Food Co-op	Food	Harrisonburg, Virginia
Vito's Italian Kitchen	Restaurant	Harrisonburg, Virginia
Dave's Downtown Taverna	Restaurant	Harrisonburg, Virginia
The American Prospect	Publication	Washington, DC

During formulation of this grant project, we expected to have more Pledges at this point in time. However, we did not account for students being away for the summer which put the project's marketing efforts on hold. The project was designed to be run by students and because of that the summers are expected to be the slowest period for the project. Due to privacy issues, each organizations contact information can be given upon request by contacting Daniel Hill.

Four GEMS Energy Surveys Completed

Of the twelve Pledges, energy surveys were completed for four of the businesses using the GEMS program. Three of these organizations served as part of the pilot program while GEMS was being developed. The table below displays the results summary from these surveys along with survey attributes.

Business Pledge	Pilot/Project	Survey Duration	Number of ECMS Recommended	Total Energy Reduction Estimate
Immerge Technologies	Pilot	19 minutes	3	1,075 kWh/yr
Shenandoah Valley SBDC	Pilot	30 minutes	12	13,970 kWh/yr
OASIS Gallery	Pilot	23 minutes	11	3,058 kWh/yr
The Green Corner Store	Project	unknown	13	4,155 kWh/yr

The complete reports for each of these organizations can be found as an attachment to this report. We refrain from including the full reports for each organization within this report as some organizations wish to keep this information private. However, the following is a compiled listing of the recommendations that were made in the reports. Any item that is bold means that it was recommended to at least one of the organizations.

- Lighting
  - **Delamp unnecessary bulbs**
  - **Replace incandescent bulbs with CFLs**
  - **Install occupancy sensors**
  - **Optimize task lights**
  - **Install LED exit signs**
  - **Upgrade T12 bulbs to T8 or T5**
  - **Utilize daylight harvesting tools**
  - **Install dimmer switches**
  - Install photocell sensors
- Plug Load

- **Utilize power strips**
- **Purchase Energy Star refrigerator**
- **Set sleep timers and power options**
- Replace inefficient vending machines

- Building Envelope
  - **Weather strip doors**
  - **Caulk windows and cracks**
  - **Replace inefficient windows**
- HVAC
  - **Install programmable thermostat**
  - **Correct the date and/or time on thermostats**
  - Replace furnace filter
  - **Retro-commission HVAC systems**
- Water
  - **Install aerators on faucets**
  - Install aerators on shower heads
  - **Install low flow toilets**
  - Install a rain barrel for outdoor watering

Of the 24 possible ECMs that are looked at during an energy survey, 19 ECMs were recommended to at least one of four businesses. We feel that this further strengthens our selection of best practice and most common ECMs present to a general business.

Winner of The 2011 Force for Change Award

In late September, Green Impact Campaign was announced the winner of The 2011 Force for Change Award. The award is a national award that is given within Net Impact to recognize an outstanding project with positive social and/or environmental impacts on campuses, workplaces, or communities. The award has a strong focus on projects that use grassroots efforts to achieve results. You can read more about the award and other finalists that were considered here: http://www.netimpact.org/displaycommon.cfm?an=1&subarticlenbr=3293

As a reward, Green Impact Campaign was announced the winner of the award to the entire Net Impact community. Additionally, we received two free registration passes to the annual Net Impact Conference in Portland, Oregon. The project will continue to be marketed as the winner of the award and as an emerging project within Net Impact.

Sustainability Summit Market Research

During the 2011 Shenandoah Sustainability Summit, we conducted general market research by asking attendees questions regarding their thoughts on barriers to businesses becoming more environmentally sustainable. Unfortunately, we were unable to hold an entire group discussion on the topic, but we still conducted basic polls. The people selected were business owners or employees for the most part, along with some consumers.

Based on Summit attendees' opinion, we found that money was the biggest reason for Valley businesses not to take steps towards environmental sustainability. Most attendees felt that Valley businesses have lower incentives to implement green changes because of the low electricity costs in the Valley compared to other regions. Other responses indicated a lack of education was a barrier. But, even those responses said that the lack of education was primarily the lack of knowledge on costs and return on investments.

Valley 25x'25 GEMS credentials

Ultimately, the conclusion of this grant project results in Valley 25x'25 gaining full access to use the GEMS program developed. The credentials below allow any Valley 25x'25 member or student volunteer to use the system to perform energy surveys for organizations in the Valley. This access also allows Valley 25x'25 full access to the ECM Catalog which is uploaded to the GEMS website.

The following login credentials are unique to Valley 25x'25 and have not been shared with anyone else. You may log in to GEMS by going to http://gems.greenimpactcentral.com/ and using the following credentials.

Username: Valley25x25
Password: 25x25

For more detailed use of the program, please reference the guides and materials previously discussed that instructs proper use of the program.

Benefits

The benefits of the resulting Green Impact Campaign project have not been fully recognized at this point. During the grant period, the focus was to develop the materials, the workflows, the systems, and the packaging of the project. The project is now beginning to be implemented and will begin to show the following positive impacts.

Local

James Madison University

The research conducted and compiled from this project are available to the various departments of James Madison University. For academia, this project has created both a base and a working model for classroom projects. The knowledge and project can be built further up by students completing class projects that would enhance the ECM quantity and applications of the recommendations. Additionally, tools such as GEMS can be used by professors to teach green building lessons with a hands-on component. For environmental departments such as ISNW and IEER, GEMS and the Campaign structure can be used by staff to engage businesses and showcase efforts present at JMU with regards to energy efficiency outreach. For JMU as an institute, the Force for Change Award helps the university gain global recognition for its students and innovation in social and environmental efforts.

JMU Students

The students that participated in the research of this project have gained experience in research methodologies and green industry job training. By participating in the research and compilation of ECM factsheets, the students involved learned about current technologies present in the green buildings industry. They learned how to conduct proper research and convey technical data in a comprehensible message to a general audience. They participated in a virtual team environment that provided them with excellent real world job experience. In the virtual team, they learned about efficient communication and time management.

For JMU Net Impact students that are beginning to implement the project in the community, they will gain the same green buildings knowledge as well as project management skills.

Shenandoah Valley Small Businesses

The small businesses that have already participated in this project gained the benefit of public recognition and/or energy efficiency information. The three businesses that received an energy survey benefited from gaining information for free that allowed them to identify opportunities available to their organization that will reduce operating costs, reduce their carbon footprint, and improve their sustainable business practices. As a whole, their total energy reduction opportunities could have the following impact on the community if implemented:

- 22,258 kWh/yr
- $2,267/yr
- 26,042 lbs. of CO_2 emission offset
- 521 new trees planted
- 20,234 car miles taken off the road

The other organizations who took the Green Impact Pledge benefited from the free publicity they received by being promoted with the Campaign in the community. Through the website and Facebook page, their organization was viewed as participants in a project that deals with businesses taking action to become more environmentally sustainable. Additionally, these organizations were given a sustainability pledge that could be implemented into the organization to further strengthen their greening efforts.

Harrisonburg Community

As a whole, the Harrisonburg community benefited from the efforts of this project and the participating organizations. Our involvement in the community has furthered Harrisonburg community's efforts to become a sustainability driven community in the Valley. The community now has the benefit of a free service available to their businesses to help identify energy efficient opportunities within their businesses. This is typically a costly service; instead this project is performing the service for free while giving students hands on experience.

Additionally, Green Impact Campaign has interacted and assisted various other projects and organizations in the Harrisonburg community. One such project is the SV Energy Partnership which is working to provide green job training to students, unemployed individuals and employed individuals in the Shenandoah Valley. We have benefited this project by lending a direct connection between the SV Energy Partnership and JMU students participating in the Green Impact Campaign.

Commonwealth of Virginia

The Commonwealth of Virginia benefits from this project as it is now a packaged outreach program that any organization, student club, or governmental body can participate in. We have developed the materials and tools in a way that any group of volunteers can bring this project into their community. Development of a community outreach project can be a costly and timely task for any entity. The state benefits from our efforts because this project is commercially available to organizations across the state.

For example, Virginia has an extensive network of Small Business Development Centers to aid and assist small businesses. The Shenandoah Valley SBDC is currently promoting Green Impact Campaign as a resource available to small businesses in the Shenandoah Valley. Other SBDC offices across the state can now add this as a free resource to strengthen their assistance to small businesses in their service area. Additionally, this project extends Valley 25x'25's efforts because any recognition received is connected to Valley 25x'25 for being the funding sponsor of the project.

National and Global

The project's unique "project-in-a-box" style allows any student club or organization to implement this outreach project in their community. The benefits at the participating schools can already be seen in the knowledge and training that the students have begun to experience. As the school year develops, these students will begin to implement the project in their community and help to benefit local businesses.

Recommendations for Further Research

Upon completion of this grant funding period, our research team is looking to further develop on our research and project in the following ways.

Additional tracking of business implementations

Due to the low number of organizations who received energy surveys, time did not permit these organizations to have enough time to implement the recommended ECMs in their organization. Because of this, we plan to closely track the organizations that have already participated as well as develop a more comprehensive follow up process for future organizations. We want to track if the organization has implemented any recommendations, what type of results they have seen from implementations, and the reasoning for which changes to implement. We feel that the follow up process will become the most vital step in Green Impact Campaign since it bridges the gap between an opportunity being recommended and a change being realized.

Further refine GEMS existing capabilities

Moving forward, we are looking to further develop GEMS existing capabilities. This includes enhancing what has already been developed by refining the system. One refinement is to continuously check the assumptions and formulas that are used to calculate energy reduction estimates. In addition to continuous checking, we would like to further improve calculation estimates by adding additional input fields that would allow for more information to be gathered during the site survey. Another refinement we are looking to add is the option for international unit conversions. Since Green Impact Campaign is being implemented internationally, the system's units are inconsistent with their units. By adding a simple feature that would convert the units from SI to metric, the information would be more relevant.

Integrate project management tools into GEMS

Currently, the Green Impact Campaign project provides information to get an organization started in greening efforts. Looking forward, we want to extend the steps in the process that Green Impact Campaign assists. We want to integrate a project management feature into GEMS that would help these organizations take the information they've been given and manage the process. The project management tool would integrate directly into GEMS and would have the following features:

- *Service Provider Directory* – After an organization receives their ECM recommendations, they need to take the next step in implementing the ECM. For some organizations, they may not know where to go for this. The Service Provider Directory would be a listing of local energy and green service providers in their area. They would be categorized based on specific ECM recommendations. This way, organizations can locate a service provider or distributors that can help them implement an ECM.
- *Utility Tracker* – The utility tracker feature would allow an organization to login to GEMS and input their current utility bills. Users would log any ECMs that have been implemented and the date that corresponds to the implementation. The utility tracker would then compare current bills to previous bills and track savings with the timing of ECM implementations.

Add additional survey topics

Further in time, we would like to add additional survey topics to the program. Currently, energy is the primary focus with little attention to water and recycling. Once we have the energy survey to a point of complete development, we want to add other topics such as environmental regulations, recycling, safety, and behavioral programming. We believe that the workflow and process that has been developed is capable of being replicated for other topics. In this way, Green Impact Campaign would be more than just energy and could serve as a more complete small business consulting resource.

Potential Funding Sources

The project model we have developed most closely matches a charitable 501(c)3 nonprofit model. As we have considered monetizing aspects of the model to continue to support the project, we see several barriers for this option to work. Since the outreach and energy survey component of the project is performed by remote student volunteers, we face quality and liability issues if the service was a paid service. Even though we have equipped student volunteers with the necessary information and tools to conduct a quality energy survey, we still have no control over the students physical actions while in the place of business. Additionally, the over-arching objective of this project is to offer a free service to organizations that may lack the appropriate budget for such services. If we monetize the energy survey, we would negate the purpose of the project.

That being said, we believe that grant funding is the best possible source for additional project funds. We see the following options the best potential sources.

Fiscal Sponsorship/Partnership

Since gaining a 501(c)3 status is a timely, costly, and unsure process, we believe our best option for gaining additional grant funding at this time would be to seek and partner with a fiscal sponsor. Fiscal sponsorships allow projects to use an existing 501(c)3 organization's status to bid on grants while in return, providing the sponsor with a small fee from any received grants. In addition, fiscal sponsors can provide the project with professional services such as legal advice and tax services. Gaining a fiscal sponsor can dramatically cut down the time before being eligible to bid on grants as well as relieving much administrative work and liability of the project. We are currently researching fiscal sponsors who match the objectives and goals of our project. Upon successfully identifying a strategic sponsor, we plan to enter into the partnership in order for us to begin submitting for available grants.

Utilities/Electric Cooperatives

Many of the utilities and electric cooperatives across the country have a charitable foundation component that gives out small grants to community projects that are working to improve energy efficiency or environmental quality in their operating area. Since Green Impact Campaign spans such a large geographical area, we believe that we could receive multiple grants from various utilities or cooperatives across the country where we have participating student chapters. Most if not all utilities only give these grants to 501(c)3 organizations, which further strengthens our plan to seek a fiscal sponsor.

Energy/Environment Foundations

Various charitable foundations have a specific focus on energy and/or the environment. We believe that our project model could make us an attractive recipient for these funding opportunities because we combine community outreach with student involvement with small business focus, all of which center around energy and the environment. Energy and environment foundations also exclusively give out grant funding to 501(c)3 status organizations. However, grants provided by these foundations are typically larger than those of a utility and tend to extend for a larger project period.

Conclusions

Upon completion of this grant project, a fully operational community outreach project has been developed that is scalable across the county. Green Impact Campaign is an innovative training program that allows students to perform energy audits for local businesses in their community. The program is centered around a web-based platform that requires no previous energy auditing knowledge and is capable of completing a full audit in less than one hour. Local businesses receive free energy efficiency advice, students gain real world hands on green job experience, and both are working to make a positive impact on the planet.

Through a strategic partnership with Net Impact, the project is currently being implemented in twenty different universities across the world. In the near future, we expect these students to begin engaging local businesses in their community and maintaining the project over the course of the school year.

Moving forward this project will seek additional funding from fiscal sponsors and public grants. In this way, we can work to continue and improve upon the development that has been made thus far.

Appendix

Sample report generated by GEMS

Green Impact Survey Report

Test, Inc.

Date completed: August 26, 2011
Conducted by: GWU-NetImpact

NET IMPACT SCHOOLS OF BUSINESS

Savings Breakdown Estimations by System

Lighting	Plug Load	Building Envelope	HVAC	Water
1,780 kWh yearly	2,440 kWh yearly	4 % of HVAC costs	10 % of HVAC costs	6,750 gallons yearly

For a more detailed savings, please input your average* monthly electric bill: $ 1000 Calculate

Energy Conservation Measures Checklist	Qty	Total Savings	Cost Savings	Annual Savings	Progress
Install programmable thermostats	0	10 % of HVAC costs	$400	3.3 %	☐
Set computer sleep timers & power save options	4	2,440 kWh yearly	$209	2.5 %	☐
Caulk windows and cracks	0	4 % of HVAC costs	$160	1.3 %	☐
Replace Incandescent bulbs with CFLs	8	1,248 kWh yearly	$107	1.3 %	☐
Install low flow toilets	2	6,750 gallons yearly	$41	Unk	☐
Optimize task lighting	4	340 kWh yearly	$29	0.3 %	☐
Install LED Exit Signs	2	192 kWh yearly	$16	0.2 %	☐
Green Behaviors					☐
Green Policies					☐
Green Opportunities					☐
What should we be recycling?					☐
How do we get others to recycle?					☐

Save progress

TOTAL POTENTIAL SAVINGS: **10,762 kWh/yr** **$962 /yr**
9 % Annual savings of energy consumption

Your Green Impact

12,592 lbs CO2 emissions

252 trees planted

9,784 miles driven

* Estimated figure. Actual figures are subject to many conditions and may vary

Electric Vehicle Energy Usage Modeling, Simulation, and Testing for Range Estimation

Robbie Hurlbrink (School of Engineering)
Lee Winslow (Geographic Science)
Dr. Robert Prins (School of Engineering)

Abstract-Electric vehicles show significant promise as a viable means of transportation. They use their stored energy more efficiently than their typical internal combustion engine powered counterparts, and are classified as having zero point of use emissions. While concerns about their ultimate energy source are well founded, electric vehicles are positioned to take advantage of a wide range of renewable energy sources since many such sources produce electrical energy. One of the largest consumer concerns related to electric vehicles is their perceived lack of range. Although range estimates for particular vehicles are available these estimates may be unreliable, especially if the vehicles will experience duty cycles that are dissimilar to standard test duty cycles. Speed, load, and topography all play a significant role in the real range of an electric vehicle. Fleet managers and other potential owners do not have a reliable way to estimate vehicle range prior to purchase and operation. The current approach to range modeling is typically based on fixed duty cycles such as SAE J1711 [1] or Federal Urban Driving Schedules [2]. While such duty cycles provide valuable comparative data they do not typically correlate to the real duty cycle that a particular vehicle is subject to. This paper explores a novel energy usage modeling approach that could be applied by fleet managers and other owners to help them make appropriate decisions regarding electric vehicle deployment. Two James Madison University students, one from the School of Engineering and the other from the Geographic Science program, modeled vehicle road loads for an electric utility vehicle and modeled route elevation and travel speed for the vehicle route. The model parameters were used to develop a simulation of vehicle energy requirements along the route. Road testing was performed along the modeled route to validate the simulations. Results show good correlation between actual energy usage profiles and simulated energy usage profiles. The total simulated energy along the route was 0.52 kJ while the actual energy usage was measured to be 0.50 kJ.

The full length paper includes the results shown in the extended abstract as well as results based on route models developed from additional mapping devices.

I. Introduction

Our goal is to accurately simulate energy usage along potential routes of travel in order to develop a range model that can be applied to a vehicle that travels a known route. This paper is focused on the modeling, simulation, and testing of energy usage of an electric utility vehicle as it travels on a route on the campus of James Madison University (JMU). Our test vehicle was a Vanguard utility truck with a 72V x 192 Ah lead acid battery pack, a Curtis controller, and an HPEVS AC-50 three phase electric motor. Although this system supports regenerative braking, we suppress regenerative braking during our tests.

Simulation of energy usage requires a route model that accounts for elevation and speed profiles as well as a vehicle model that accounts for road loads. Route modeling was accomplished by traveling the route with GPS tracking devices and also by using USGS database data. Our tracking devices provided updated data at a frequency of approximately 1 Hz. Our vehicle model accounts for road loads due to rolling resistance, aerodynamic drag, and elevation changes as well as motor/controller efficiency. While most road load parameters were directly measured, other parameters, such as drag coefficient, are book values. During road tests, battery pack voltage and current were monitored to provide a running tally of energy usage.

II. Methods

This section describes our route and vehicle models, our simulation, and our road testing protocol.

A. Vehicle Model

Our vehicle model is based on the road load force applied to the vehicle. Road load force summarizes the forces that act to on a vehicle that are aligned with the travel direction of the vehicle. Mathematical models of road load forces are described in various texts, we relied on the modeling approach described in [3]. In short, the road load force is the sum of the force of rolling resistance, the force due to drag, and the force due to gravity as shown in (1). Rolling resistance refers to contact between tire and road surfaces, drag is due to wind resistance, the force of gravity accounts for force required to change elevation.

$$F_{RL} = F_R + F_D + F_G \quad (1)$$

Where:
F_{RL} = Road load force
F_R = Rolling resistance force
F_D = Force due to drag
F_G = Force due to gravity

The force of rolling resistance is due to the friction from the tires rolling along the pavement. While this may be affected by some factors such as tire pressure, pavement characteristics, and tread conditions, we maintained consistent tire pressure and assumed variations in the other factors would be negligible. The force of rolling resistance is the product of the weight of the loaded vehicle and the rolling resistance coefficient as shown in (2).

$$F_R = W \times f_r \quad (2)$$

Where:
F_R = Rolling resistance force
W = Weight of loaded vehicle
f_r = rolling resistance coefficient

The weight of the loaded vehicle was measured using the drive-on scale of a local lumber company; the measured weight was 14055 N (3160 lb). The rolling resistance was determined through low speed coast down testing to be 0.017.

The force due to drag accounts for wind resistance and is dependent on the density of air, the shape of the vehicle, the frontal area of the vehicle, and the air speed of the vehicle as shown in (3). The effect of the shape of the vehicle is accounted for by the drag coefficient.

$$F_D = (1/2) \times \rho \times c_d \times A \times v^2 \quad (3)$$

Where:
F_D = Force due to drag
ρ = air density
c_d= drag coefficient
A = frontal area
v = air speed

Air density was determined based on temperature, pressure, and humidity conditions as provided by a weather station. Drag coefficients can be directly measured in wind tunnels, or determined from coast down tests. Our vehicle speed was limited to ~11.5 m/s (25 MPH) which we determined was too slow to get reliable coast down data for drag force. We used a book value of 0.45 associated with pickup trucks found in [3]. The frontal area was determined by direct measurement of the vehicle; we found the frontal area to be 2.164 m^2. Although we attempted to measure air speed using a pitot-static tube arrangement we were unable to get reliable air speed data using this system. Fortunately our testing was done in calm conditions so that air speed could be well approximated by ground speed. Ground speed was determined by both GPS and by monitoring the motor speed.

The force due to gravity accounts for changes in elevation and is dependent on vehicle weight and change in elevation as shown in (4).

$$F_G = W \times \sin(\theta) \quad (4)$$

Where:
F_G = Force due to gravity
W = Weight of loaded vehicle
θ = angle of road

The weight of the loaded vehicle was measured as described above; the road angle was based on sequential GPS measurements of position and elevation.

The total road load is found by substituting (2), (3), and (4) into (1) as shown in (5).

$$F_{RL} = W \times f_r + (1/2) \times \rho \times c_d \times A \times v^2 + W \times \sin(\theta) \quad (5)$$

B. Route Model

The route model consists of the elevation profile of a path as well as an expected speed profile of the vehicle along the path. The elevation and speed profiles for the route were determined by traveling the route with a GPS tracker while maintaining typical speeds. The GPS tracker provided position and elevation data at 1Hz intervals that could be used to determine the elevation and speed profiles.

The GPS units used to conduct this study were Trimble Geo XH and a Garmin eTrex Vista. The Trimble Geo XH is a survey grade GPS unit. During the study it was typical to acquire 5-6 meter accuracy before post processing the data. After post processing the data by using differential correction the typical accuracies were around 40 cm. The accuracies were the same for both horizontal and vertical measurements. The Garmin eTrex Vista was used in addition to the Trimble Geo XH to acquire a second source of elevation data to compare to the output of the Trimble Geo XH. The Garmin eTrex Vista is a recreational grade GPS which produces lower accuracy positions but has a barometric pressure sensor built in allowing for elevation readings to be taken without relying on satellites.

Another source of elevation data for the routes being run in this study was provided by the United States Geological Survey (USGS). The USGS has digital elevation models (DEM) published online that has a resolution of 10 meters. This means that in the image every 10 meter by 10 meter pixel is given an elevation value. By overlaying the point data of the routes being run in a mapping program such as ArcMap and using an extract by point tool the elevation values for each point can be extracted from the DEM to the route data.

In all, four separate measurements of elevation data were used to develop route models during the study. The four elevation profiles being created were the Trimble uncorrected, Trimble differentially corrected, the Garmin barometric pressure sensor, and the USGS DEM. It is important to note that the USGS and both Trimble Geo XH data sets are measuring absolute elevation while the Garmin GPS is measuring change in elevation. This means that while the elevation profiles and slopes are expected to have similar shapes, their absolute values may differ.

C. Simulation of Energy Usage

In order to simulate energy usage we used (5) to calculate the road load force for each time interval and multiplied this value by the distance traveled during the time interval. We used an interval of one second to correspond with our GPS tracking data, the distance travelled during each interval was taken as the straight line distance between corresponding GPS locations as reported by the GPS unit. Equation (6) shows the equation used to simulate energy usage at the wheel over an arbitrary interval *i*.

$$\Delta E_{\text{wheel } i} = [W \times f_r + (1/2) \times \rho \times c_d \times A \times v_i^2 + W \times \sin(\theta_i)] \times \text{distance}_i \quad (6)$$

Since (6) is based on workload at the wheel it does not account for inefficiencies of the drive system , in order to determine the energy required from the battery pack we applied an efficiency factor based on published data from the motor manufacturer that correlates efficiency to motor RPM at peak load according to (7).

$$\Delta E_{\text{battery } i} \times \eta = \Delta E_{\text{wheel } i} \quad (7)$$

Where:

$E_{\text{battery } i}$ = Energy provided from battery pack over i_{th} interval

η = drive efficiency

$E_{\text{wheel } i}$ = Energy required at wheel over i_{th} interval

The total energy used along a particular route is the summation of the $\Delta E_{\text{battery } i}$ values across all of the intervals.

D. Road Tests

In order to validate the simulation results we monitored vehicle energy usage as measured at the battery pack. Pack energy output was determined as the product of pack voltage and pack current which were measured at a frequency of 1Hz while driving the route.

III. Results

Our results include the raw speed and elevation data used to construct the route model, simulated energy usage as calculated by (6) and (7), and actual energy usage as determined by battery pack monitoring. Figure 1 shows a typical set of elevation and speed profile data for a particular route along with the corresponding simulated energy usage.

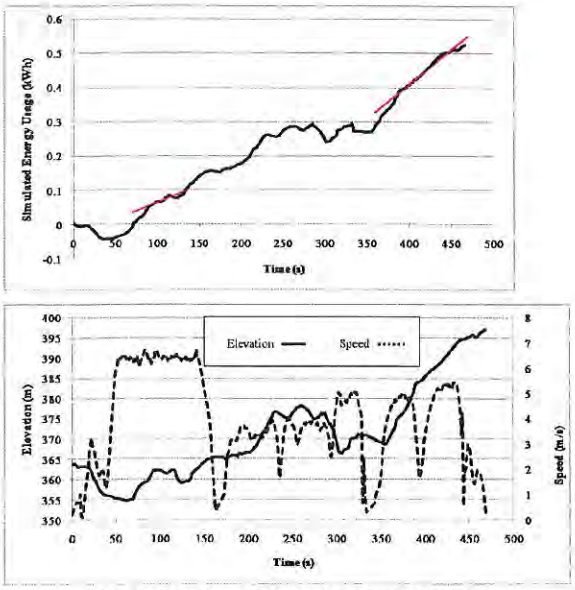


Fig. 1. Elevation and speed profiles of route

Figure 1 shows the dependency of energy usage on route elevation and speed profiles. The segment near 100 s is modeled as nearly flat with a constant speed of ~11.5 m/s (25 MPH), the corresponding segment on the energy graph shows that energy usage climbs at a steady rate. Also note the segment near 425 s, the road increases in elevation while speed is maintained at a constant ~9 m/s (20 MPH), in this segment the energy usage occurs at a higher rate.

The simulated energy usage as shown in figure one was compared to actual energy usage as measured at the battery pack. Figure 2 shows both data sets on the same set of axes.

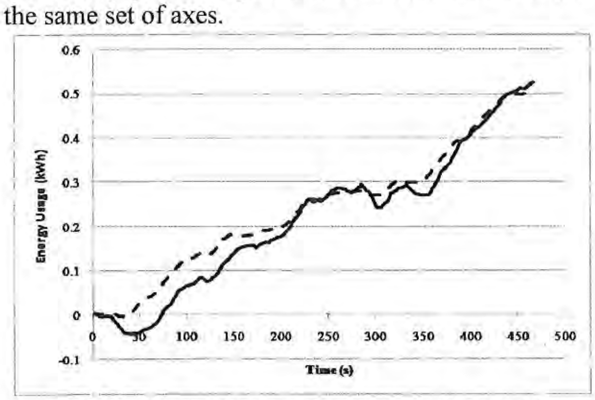


Fig. 2. Simulated and measured energy usage along route

Figure 2 demonstrates that the model predicts the measured energy usage reasonably well. At the end of the route the total energy usage predicted by the simulation is 0.52 kWh in comparison to a measurement of 0.50 kWh of energy used.

IV. Discussion

Although our approach provided us with reasonable output, several challenges remain. Noise that is inherent to GPS based elevation data can cause further problems when calculating road inclination angle. When observing modeled road angle data we frequently encountered road gradient values that were significantly larger than any real gradient along the route. Although filtering can be used to eliminate some of these effects, it also tends to eliminate real elevation features.

Figure 1 shows that our energy consumption closely follows our elevation change. This is so because of our reduced speeds, reliable output for routes that include higher speed profiles would rely on accurate drag force coefficient values.

V. Conclusions

An energy usage model that accounts for the real path of an electric vehicle was applied to a small electric powered utility vehicle. A simulation of energy usage based on vehicle road loads and an elevation and speed profiles of the travel route provided a plot of energy usage predictions. The simulation and modeling was validated by road tests in which the route was traveled while energy flow from the battery pack was monitored. At the end of the route the total energy usage predicted by the simulation is 0.52 kWh in comparison to a measurement of 0.50 kWh of energy used.

Acknowledgements

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Preliminary Performance Analysis Of NoNOx Water Fuel Emulsion Device

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Introduction

The technology of water fuel emulsion has a long history. In fact, it has been experimented with since the 1930s (1). Because of rising fuel prices and increased environmental concern/awareness efforts have increased greatly in the past decade. A brief investigation of recent publications finds numerous university studies on the effects of mixing water into fuel, as well as many companies marketing either emulsified fuel or fuel emulsifying systems. Some of these later make rather bold claims: fuel savings of as much as 24% and reductions in emitted NO_x and particulate matter of up to 80% (2, 3). Regardless of how improbable some of these marketing claims may seem, the university studies do support the generalized claim that emulsifying water with fuel can reduce emissions and improve fuel economy (1, 4, 5).

The goal of the tests performed in this study was to evaluate the effects of the $NoNO_X$ fuel emulsion system on fuel economy and exhaust emissions. The $NoNO_X$ system emulsifies water into gasoline or diesel fuel, with the goal of reducing both fuel consumption and exhaust emissions. Tests were conducted to measure fuel consumption, and emission levels of carbon dioxide (CO_2), carbon monoxide (CO), mono-nitrogen oxides (NO_X), and particulate matter.

Methods

The $NoNO_X$ system used for testing was a Model 50 emulsion unit installed on Truck 39, a 2003 Mack CX-600 tractor-trailer cab, equipped with a Mack E7-460 engine, belonging to Wholesome Energy. Testing was carried out at Antrim Diesel in Greencastle PA, using their Taylor TD-36 water-brake semi-truck chassis dynamometer. Speed and power were kept uniform across all tests with less than 0.2% variation. It is therefore reasonable to believe that differences in the measured parameters detailed below are primarily due the use of emulsified fuel, rather than being attributable to variation in testing conditions. Figures 1 though 4 show components of the testing apparatuses. The following sections deal with the statistical testing used to determine the significance of the data.

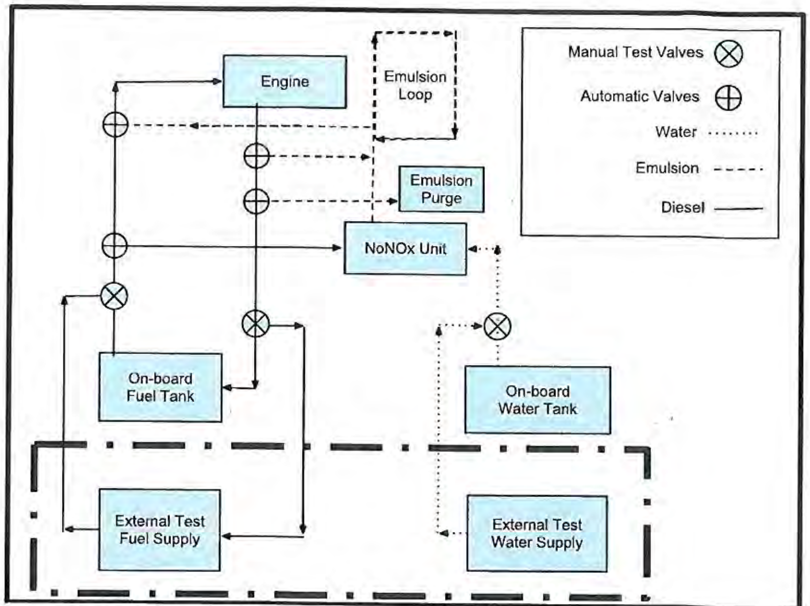

Figure 1: diagram of Truck 39 fuel/emulsion system. The automatic valves are electronically controlled solenoid selector valves used to switch from diesel to emulsion. The emulsion loop continuously recirculates any unused emulsion back into the $NoNO_X$ unit to be re-emulsified. The emulsion purge tank is used when switching to diesel from emulsion in order to prevent any water from being returned to the on-board diesel tank. The manual test valves were used to select between the on-board fuel and water tanks and the external measured fuel and water supplies during testing. The heavy dot-dash line indicates those components not permanently installed on the truck. See figures 3 and 4.

Figure 2: wider view of the 2003 Mack CX-600 semi-truck mounted to the Taylor TD-36 water-brake dynamometer. The emulsion system is visible in the center of the frame, beside the forward set of wheels. The device in the foreground to the right was used to measure particulate matter in the exhaust.

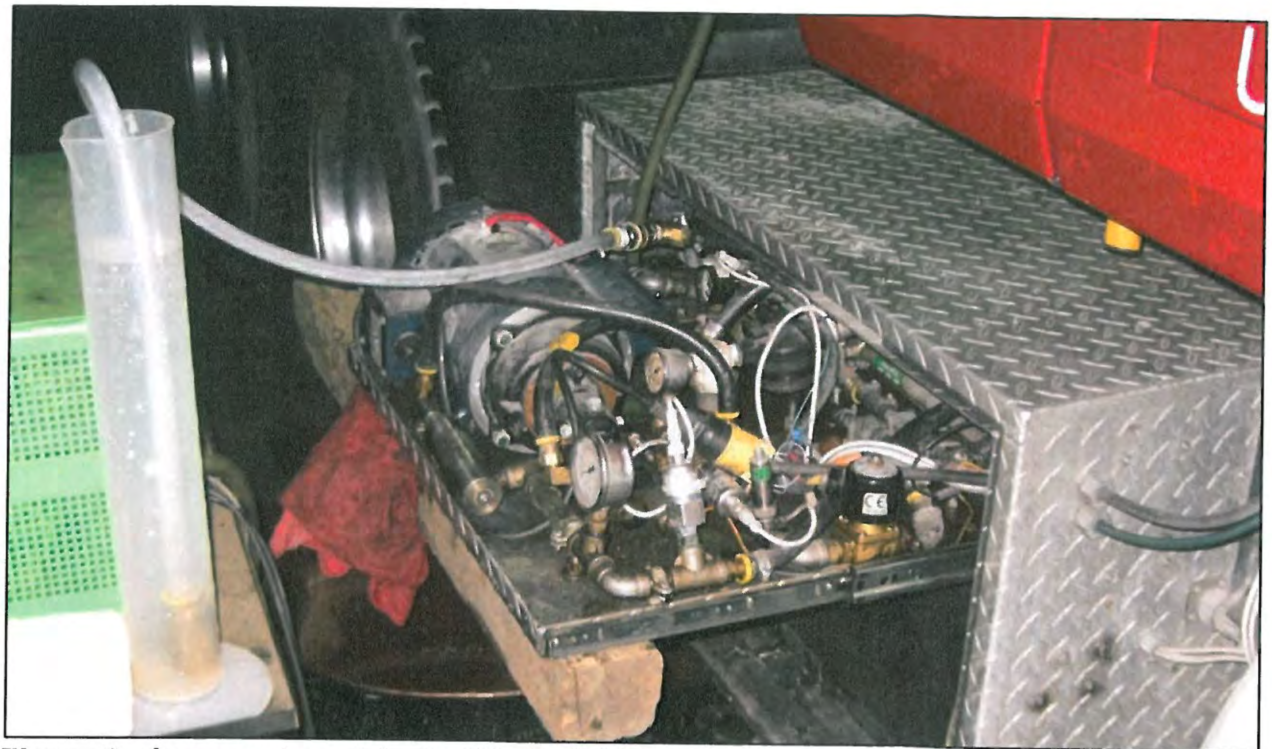

Figure 3: close-up view of the NoNOx Model 50 emulsion device mounted to the right-hand side of the 2003 Mack CX-600 truck. The graduated cylinder to the left of the frame was used to quantify the amount of water entering the system during testing.

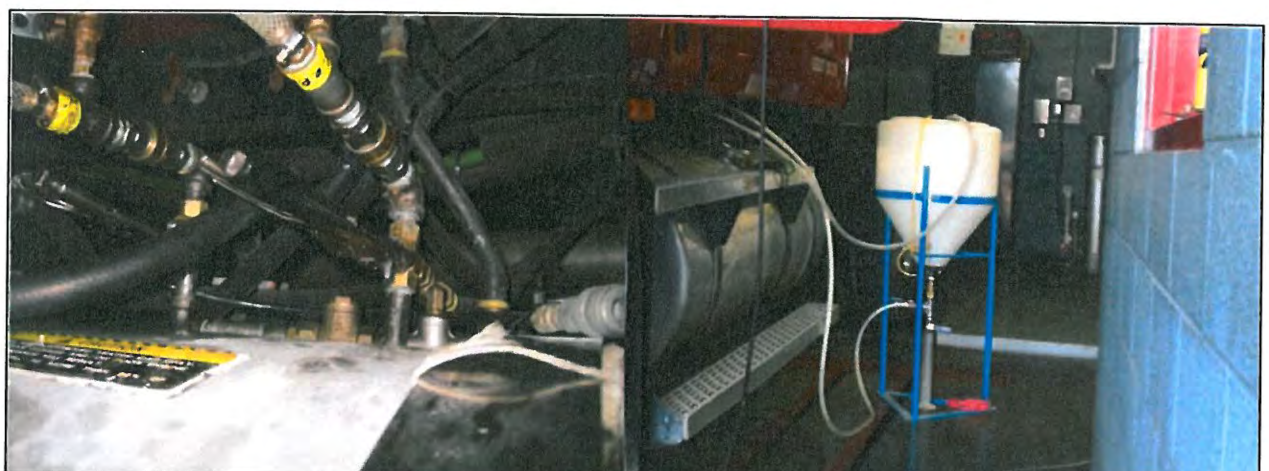

Figure 4: Left: close-up view of manual fuel control valves used during testing. Right: external measured fuel supply cone.

Results and Analysis

The average testing speed was 59.97 mph with a standard deviation of 0.095 mph (0.16% variation), and the average test power was 192.24 hp, with a standard deviation of 0.227 hp (0.14% variation). The proportion of water, as a percentage of total emulsion volume, averaged 14% with a standard deviation of 0.64% (4.6% variation). Statistical tests were preformed using the R statistical testing software package. All tests used were two-sample t-tests. Those used to check specifically for a higher or lower parameter value were one-tailed tests. Those used to look for any difference in mean parameter values were two-tailed tests. Table 1 summarizes the data collected during testing.

Table 1: data collected. E denotes the values from tests using emulsion. D denotes the values from tests using diesel. Δ (E-D) shows the difference between the emulsion and diesel values: a positive number means an increase in the parameter when using emulsion, a negative number indicates a decrease. Percentage changes (% Δ) are listed relative to the values from tests using diesel.

Fuel Economy (miles/gallon)					
	E	**D**	**Δ (E-D)**	**% Δ**	**p-value**
Average	5.30	5.45	-0.15	-2.75%	0.05007
Stand. Dev.	0.22	0.19			
Exhaust Gases: CO_2 (%)					
	E	**D**	**Δ (E-D)**	**% Δ**	**p-value**
Average	8.29	8.18	0.11	1.34%	<0.05
Stand. Dev.	0.55	0.19			
Exhaust Gases: CO (ppm)					
	E	**D**	**Δ (E-D)**	**% Δ**	**p-value**
Average	37.59	71.99	-34.40	-47.78%	<0.001
Stand. Dev.	17.91	31.17			
Exhaust Gases: NO_x (ppm)					
	E	**D**	**Δ (E-D)**	**% Δ**	**p-value**
Average	917.79	860.61	57.18	6.64%	<0.001
Stand. Dev.	89.17	83.59			
Particulate Matter: Percent Opacity (%)					
	E	**D**	**Δ (E-D)**	**% Δ**	**p-value**
Average	1.38	2.76	-1.38	-50.0%	<0.001
Stand. Dev.	0.410	0.217			
Particulate Matter: Concentration (mg/m3)					
	E	**D**	**Δ (E-D)**	**% Δ**	**p-value**
Average	13.4	28.1	-14.7	-52.3%	<0.001
Stand. Dev.	4.351	2.234			

Fuel Economy

Three t-tests were performed on the fuel economy data. The hypotheses evaluated were: that there was no change in fuel economy between using diesel and emulsion, that there was an increase in fuel economy with emulsion, and that there was a decrease in fuel economy with emulsion. Each test gave a p-value, reported in Table 2; a lower p-value corresponds to greater confidence in accepting the hypothesis of that test.

The lowest p-value was p=0.05007, for the hypothesis of lower fuel economy using emulsion. This agrees with a visual comparison of the mean fuel economy with and without emulsion, Table 1. However, a typical level of significance for t-tests is 0.05; this corresponds to being willing to mistakenly reject the null hypothesis 5% of the time. If p is less than the level of significance then the difference can be considered statistically significant. The p-value from this test is greater than 0.05, which suggests that no statistical difference can be detected between the two fuel options.

Table 2: hypotheses and p-values for fuel economy tests

Hypothesis tested	**p-value**
Higher fuel economy with emulsion	0.9499
Notable change in fuel economy	0.1001
Lower fuel economy with emulsion	0.05007

Exhaust Gases

CO_2

The same three t-tests were used on the data for CO_2 emissions, Table 3. The lowest p-value was p=0.04098, for higher CO_2 emissions using emulsion. Therefore it does appear that CO2 emissions were higher with emulsion. The average CO_2 increase was 1.32%.

Table 3: hypotheses and p-values for CO_2 emissions tests

Hypothesis tested	**p-value**
Higher CO_2 emissions with emulsion	0.04098
Notable change in CO_2 emissions	0.08196
Lower CO_2 emissions with emulsion	0.959

CO

The same three t-tests were used on the data for CO emissions, Table 4. The lowest p-value was for lower CO emissions using emulsion, p=5.683e-10. Because the p-value for this test is so much lower than 0.05 we can use a much stricter level of significance. For example, 0.001 corresponds to being willing to mistakenly reject the null hypothesis only 0.1% of the time. The average CO decrease was 47.8%.

Table 4: hypotheses and p-values for CO emissions tests	
Hypothesis tested	**p-value**
Higher CO emissions with emulsion	1
Notable change in CO emissions	1.137e-09
Lower CO emissions with emulsion	5.683e-10

NO_X

The same three t-tests were used on the data for NO_X emissions, Table 5. The lowest p-value was for higher NO_X emissions using emulsion, p=7.649e-06. Because the p-value for this test was again so much lower than 0.05 we can again use a much stricter level of significance. The average NO_X increase was 6.64%.

Table 5: hypotheses and p-values for NO_X emissions tests	
Hypothesis tested	**p-value**
Higher NO_X emissions with emulsion	7.649e-06
Notable change in NO_X emissions	1.53e-05
Lower NO_X emissions with emulsion	1

Particulate Matter

Two parameters were used to measure the level of particulate matter in the exhaust. The first was concentration of particles, measured in mg/m^3. The second was the percent opacity of the exhaust. The same three t-test configurations were used on the particulate matter data, Table 6. For both metrics, the lowest p-values were for lower particulate emissions using emulsion: p=1.233e-07 for particle concentration, and p=1.219e-07 for percent opacity. This means we can once more use the much stricter level of significance 0.001, therefore we will mistakenly reject the null hypothesis only 0.1% of the time. There was a 50% reduction in the average percent opacity of the exhaust, and a 52.3% reduction in the average concentration of particulate matter in the exhaust.

Table 6: hypotheses and p-values for particulate matter tests	
Hypothesis tested	**p-value**
Higher particle concentration with emulsion	1
Notable change in particle concentration	2.465e-07
Lower particle concentration with emulsion	1.233e-07
Higher smoke opacity with emulsion	1
Notable change in smoke opacity	2.438e-07
Lower smoke opacity with emulsion	1.219e-07

Conclusion

Based on the outcome of these tests it is reasonable to state that the NoNOx system does have the positive effect of reducing emission of particulate matter. Fuel economy appears to have been slightly reduced; however, this negative effect may be outweighed by the particulate emission improvements. The changes, both increases and decreases, in the levels of exhaust gases are interesting, and also merit further investigation.
The results of these tests should be considered only preliminary. More testing is needed to determine the effects of varying parameters such as engine speed and load, and the percentage of water used in the emulsion. Additional tests using a gasoline engine are also planned.

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- Mr. Eric Cottell, NoNOx Ltd.
- Dr. Nicole Radziwill, James Madison University

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Researching and Implementing a Policy to Promote Sustainable Energy in Virginia

Submitted to the Integrated Science and Technology Program at James Madison University in partial fulfillment of ISAT - 493

By
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under the faculty guidance of
Dr. Jeffrey Tang

5/6/2011

Abstract

Policy can heavily influence the adoption of renewable energy and energy efficient technologies. The goal of this project is to work with members of the city government to implement a policy in Harrisonburg that will promote sustainable energy. Local governments are often better positioned to develop and implement innovative policies that can help solve emerging problems in a way that is appropriate for the community. After researching and analyzing several local policy options, Property Assessed Clean Energy (PACE) financing was chosen as a potential policy option for Harrisonburg. With the enabling legislation already passed at the state level, PACE was selected because its efficacy and its political viability in Harrisonburg. Traditional PACE programs function by the locality lending money to property owners for clean energy upgrades. After discussions with a city council member, I decided to propose a commercial PACE program funded by private lenders. Implementing this policy would allow Harrisonburg to serve as a model for other cities around the state.

Contents

Introduction

In the face of the current energy situation, two of the main issues confronting energy in the United States and Virginia in the coming years are building a renewable energy portfolio and increasing energy efficiency. These are both components of a more sustainable energy portfolio. As we move into the future, the necessity of sustainable energy will continue to increase. More sustainable forms of energy production and use will be needed to replace fossil fuels and take advantage of cleaner sources of energy. Before continuing, I feel it is important to give a definition for the idea of sustainable energy. John Randolph and Gilbert Masters provide a good definition for the term sustainable energy in saying, "Sustainable energy refers to those patterns of energy production and use that can support society's present and future needs with the least life-cycle economic, environmental, and social costs" (Randolph and Masters 2008). The current energy situation is a large and complex issue which will require a multitude of technologies, policies, and other innovations to tackle.

The goal of this project was to work with members of city government to implement a policy in Harrisonburg that will promote sustainable energy. I wanted to help position Harrisonburg as leader in the development and use of sustainable energy in the Shenandoah Valley and Virginia. Overall, I wanted to research and propose a program that had a real chance of getting implemented in Harrisonburg, as well as one that could have a lasting and significant impact.

Selecting a Policy

My first objective was to determine the scope of this project. I had to decide what governmental level, national, state, or local, I would try to work with to develop and implement a policy. Working towards a national level policy was ruled out right away. As an individual, I simply did not have the connections or influence on the national level, therefore it would be nearly impossible to get anything accomplished on the national level during a 15-month time frame. Another option I considered was to identify a state level policy to research and implement. However, there were concerns as to the feasibility and practicality of trying to implement a state level policy within the time constraints of a capstone project. I would have had little time or ability to travel to Richmond to work and meet with key players in Virginia politics. Given the legislative calendar in Virginia, I felt that there would not be sufficient time or opportunity to be able to develop a proposal and implement a policy. As a result, I decided to work on identifying and implementing a local-level policy in Harrisonburg.

A problem as sweeping and complex as the energy crisis would seem to require the power and authority of the federal government to solve. However, in the US, the federal government has been largely idle on the issue. While over the past few years there have been attempts at addressing the energy situation, a national energy strategy has not yet been developed. In that sense, it is up to the state and local governments respond to the issues and begin working on solutions. State and local governments are not plagued with some of the problems that hamper progress on the national level, and are thus better equipped to develop solutions to emerging problems. State and local legislative bodies are often easier to navigate and the decision making process be less complicated than at the national level. This results in state and particularly local governments being able to respond and adapt more quickly to provide solutions to emerging problems. With a smaller area of governance, localities are able to develop more customized solutions that are technically appropriate and politically feasible. States and localities can often serve as petri dishes for potential policies. When one state or locality implements a new policy, others can observe the outcome of that policy. Successful policies can then be implemented in other locations, using success in other areas as evidence for implementation.

There were several considerations made in selecting Harrisonburg as the locality to work with. One of the primary reasons was because I am currently a resident of Harrisonburg. As a resident, I am familiar with the political climate in the city, the workings of the city government, and the attitudes and opinions held by the population. The convenience of the location would allow me the opportunity to meet face to face with key members of the city government. Working with Harrisonburg would allow me to take advantage of connections within the city government. One key connection is with former mayor and current city council member Kai Degner. As a former Integrated Science and Technology (ISAT) major at JMU, he has been involved with many members of the ISAT and JMU community. Kai has also been a supporter of sustainability activities in Harrisonburg. I felt that between the existing connections and his interest in sustainability, I would be able to work with Kai to accomplish the goals of this project. Most importantly, I felt that there was a real chance to get something accomplished and to leave a lasting impact on Harrisonburg.

Once I decided to try to work with Harrisonburg to implement a policy, I needed to identify a potential policy. I began my search for a policy by looking at different localities around the country. There were a few different potential policy options considered. One policy option I looked into was the local option for exempting solar panels from local property taxes. This was a policy that had been passed at the state level, allowing localities to adopt ordinances in accordance with the state legislation. This is currently implemented in many localities across Virginia. At the time of my initial research, this policy had not been enacted in Harrisonburg. Given its prevalence throughout the state, the local property tax exemption appeared to be a good candidate for implementation in Harrisonburg. Interestingly enough, there was already a group of people who were lobbying the Harrisonburg city government to enact a property tax exemption ordinance. The city just passed an ordinance that will exempt 100% of the value of certified solar equipment from local property taxes for 20 years (City of Harrisonburg, Virginia, §4-2-31).

Another policy option was a feed-in tariff program similar to one implemented in Gainesville, Florida in 2009 (cite properly). The feed-in tariff program stuck out as one of the first programs of its kind in the country. The Gainesville program showed early indications of success, helping to grow the renewable energy market in the midst of a recession (Blake 2009). This policy has the potential to significantly increase the implementation of renewable energy technologies. In analyzing the policy, I didn't feel it would be the right policy to propose in Harrisonburg. This is primarily because the political atmosphere in Harrisonburg is significantly different than in Gainesville, Florida. There would have been strong resistance from Harrisonburg Electric Commission (HEC) to a feed-in tariff program. This program would require HEC to pay a premium, above retail, rate for electricity generated from solar photovoltaic (PV) sources. This would have cut into HEC's revenue, which would have cut into the city's revenue, given that HEC is a municipal owned utility. Such a program would be perceived as excessive government interference in electricity market as well. In essence, a feed-it tariff program would be politically controversial in an area with typically politically conservative values. It would be extremely difficult to gain political or public support for a feed-in tariff program in the area. Overall, such a program would not have a good chance of being implemented in Harrisonburg's political climate. After researching several different local-level policies, one policy that caught my attention was Property Assessed Clean Energy (PACE) financing.

Property Assessed Clean Energy (PACE) Financing

Property Assessed Clean Energy (PACE) financing started as a pilot program in 2008 in Berkeley, California (cite). Known as the Berkeley FIRST (Financing Initiative for Renewable and Solar Technologies) program, it was the first program in the country to use the financing mechanism now known as PACE (Office of Energy and Sustainable Development 2010). The idea of PACE financing quickly caught on; since 2008, 25 states have passed PACE-enabling legislation at the state level (PACENow.org 2011). This enabling legislation allows localities to establish a PACE program via a local ordinance. The local ordinance must adhere to the limitations set by the enabling legislation. The state, in the enabling legislation, can set limitations or certain requirements for local program. For example, the Virginia PACE enabling legislation requires that the local ordinance define an upper and lower limit for the aggregate amount of financing. It also requires that a public hearing should be held prior to the enactment of the ordinance and that private lenders should be offered the opportunity to participate in a PACE program. However, it does leave the locality to determine the list of qualifying upgrades. It also gives the locality the ability to bundle the loans and transfer them to a private lender while having the lien placed on the property remain in full effect (Code of Virginia, § 15.2-958.3).

PACE Mechanics

In short, PACE functions by a locality selling bonds to raise money to loan to homeowners to finance energy upgrades, and the loans are paid by via a property tax assessment. There are a series of technical details that make it all possible. The city, or locality, raises the money for the program through the sale of municipal bonds, similar to those used to finance other public projects like roads, bridges, or public buildings. These bonds are some on the bond market. When the bond is purchased, it is essentially a loan to the municipality by the bond purchaser. The bonds pay out a set amount of interest, which is set by the issuer, and reaches a maturity, upon which the principal is paid off (Securities and Exchange Commission 2008). This feature allows the locality to leverage private funding rather than taxpayer dollars to finance the program. Also, sources of local financing can be used, thus keeping the money in the local economy. Below, Figure 2 shows the process flow for a traditional PACE financing program.

Figure 1: PACE financing flowchart (Supple and Nix 2010).

An important component of PACE programs is the existing government mechanism known as a "land-secured financing district," often referred to as an assessment district, a local improvement district. The assessment district mechanism allows the local government to issue bonds to fund projects with a public purpose (U.S. Department of Energy 2010). Under this mechanism, the local government can place assessments on properties, which are defined as "charges levied against real property by state or local authorities to fund improvements benefiting the land" (Hill 2005). A lien is attached to the property when an assessment is levied. A lien is defined as "a legal claim to secure a debt" (State of California 2011). A lien is a currently existing financial mechanism used by municipal governments for both assessment districts and tax purposes. A tax lien on a property allows a local government to hold a sale of the property in order to collect the taxes in default. In the case of PACE programs, liens are placed on the property receiving loans from the locality in the event of default on the loan payments. In the same sense, the local government would have the right to sell the property to collect on the PACE loan in the event of a default. This helps to secure the loan and lowers the potential for loss for the local government. Critical to PACE programs is the priority, or seniority, of the lien placed on the property. In PACE programs, security of the loan is provided by a senior status lien on the property. By definition, a senior lien has "priority in being paid back in full first before all other liens" (Cornell University Law School 2010). This gives the locality an added level of security and confidence in making the loan. It also ensures the locality will be able to make the payments on the bonds issued to raise money.

There are a lot of different types of improvements that can be covered by PACE programs. These can include energy efficiency upgrades such as, high efficiency windows, addition or improved insulation, and high efficiency HVAC system installation. Other potential upgrades can include renewable energy technologies such as solar hot water systems, solar PV systems, and geothermal heat pump system installations (Sonoma County Energy Independence Program 2011). Since the program is designed, developed, and implemented locally, it allows localities the flexibility to define the list of "qualified upgrades" for their own programs. This allows the localities the ability to determine what upgrades are technically and economically feasible in the area. With the localities determining the qualified upgrades, they can ensure that homeowners will get an acceptable return on investment, thus lowering risk on the loan.

There are several aspects to the administration of PACE programs. The locality has the option to determine how much of the administration is to be done in-house and how much will be the responsibility of a third-party. Administration is needed in the areas of: program design, development, and implementation, program improvement, program marketing, application development and review, bond issuance and payment, and payment collection (Fuller, Kunkel and Kammen 2009). Costs associated with administering a PACE program can vary and mainly deal with the cost of existing or new staff's time spent on the program and any costs incurred by using an outside contractor to help administer the program. However, many PACE programs are able to cover the costs of administration of the program by a combination of application fees and the difference between the interest rate charged on the loan and the interest rate being paid on the bonds issued.

Why PACE?

PACE is intriguing because it takes advantage of the powers of a locality to create an innovative financing option. In traditional PACE programs the city loans money to property-owners to install clean energy upgrades to their property. The city raises money by selling bonds and the loan is repaid to the city by an extra payment on the property tax bill. One of the main advantages to this way of financing is that the loan stays with the property as opposed to the owner. One of the reasons I chose to move forward in trying to implement PACE in Harrisonburg was the potential for bipartisan support. PACE-enabling legislation has been passed in 24 states, in both traditionally conservative and liberal states. Since 2008 25 states have passed PACE enabling legislation. Figure 2, below, shows the states that have passed PACE enabling legislation shaded in green. The states with enabling legislation include California, Colorado, Maryland, Georgia, Texas, and of course Virginia (PACENow.org 2011). PACE has a proven track record of gaining support on both sides of the aisle.

Figure 2: PACE enabling legislation across the US (Alliance to Save Energy 2010).

The efficacy of PACE was another factor for moving forward with PACE. I spoke with Patrick Cushing, former ISAT major, lawyer, and former advisor to the Virginia Legislature, who was involved in developing Virginia's PACE-enabling legislation. He has identified PACE financing as one policy that all localities in Virginia should adopt to help promote sustainable energy (Cushing 2010). There has also been support on the national level from the Obama administration. Department of Energy has publically supported PACE financing. In October 2009, Vice President Biden was quoted as saying, "We are encouraging communities to give you the option to pay the expense of retrofitting your homes through your property taxes" (McLaughlin 2009).

PACE has a lot of potential to have a meaningful impact on the adoption of sustainable energy technologies in Harrisonburg. It can promote the use of clean energy in a way that that is widely accepted, accomplishing its goal of promoting sustainable energy while helping create jobs and utilizing private funding. PACE financing helps overcome the high upfront costs and long-term payback periods that often serve as barriers to the adoption of sustainable energy technologies (Speer 2010). It also provides savings in energy costs. In some cases the savings can be greater than the loan payment, resulting in a net positive cash flow for the property owner.

The voluntary nature of PACE programs means that those who receive a PACE loan are the only members of the community absorbing the cost of the loan. This helps to avoid the fears of government mandates and interference in the market, which is a key bipartisan selling point.

Another benefit PACE financing is that it is a local program. Enabling legislation allows localities to develop a program, but it does not define the specific details a potential PACE program. This gives each locality the freedom to make appropriate adjustments to the program to optimize the benefits in each area. Localities are able to determine a wide range of program details. On a basic level, a city is able to determine the size of the program. It can range from a program that supports a small number of projects annually, to a program that is able to leverage millions of dollars of funding. As a result, localities are able to start with a smaller scale program, then as the program gains support, the locality is able to ramp-up the program as demand increases. Localities are able to determine the list of qualifying upgrades for the program to maximize the potential benefit, and savings, to the city and property-owner. Not all technologies are universally beneficial. With PACE, localities are able to select the technologies that are most appropriate for the area, such as the technologies that provide the greatest return on investment or fastest payback. For example, for a city in southern California, solar panels can be highly effective and provide excellent economic benefits. However, for a city in New Hampshire, solar panels might not make technical or economic sense. Property owners in the city in New Hampshire would probably benefit more from upgraded insulation or a high efficiency HVAC system. Therefore, the city in California would be able to allow for solar panels on the list of qualifying upgrades, while the city in New Hampshire would be able to leave solar panels off the list.

Other reasons for selecting PACE financing are the numerous benefits to both localities and property-owners. One of the benefits to a community of a PACE program is the increased community resilience. Community resilience can be defined as: "the capability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change" (Community and Regional Resilience Institute 2009). To that effect, PACE programs can increase community resilience by helping to insulate the community to shocks and increases in energy prices. One of main benefits to the locality is the creation of local jobs. This includes jobs that cannot be outsourced such as construction, contracting, and energy auditing. The Institute for Building Efficiency estimates "five direct jobs, five indirect jobs, and ten induced jobs [created] for every million dollars invested" (Supple and Nix 2010). Another key selling point of PACE financing is the ability to leverage private funding and investment in sustainable energy. The voluntary nature of PACE program ensures that only those who benefit directly from the program bear the costs of the program. This means that taxpayer dollars are not being spent on upgrades for a select group of people. The combination of private funding and voluntary participation limits the risk borne by the city under a PACE program. It also helps to make the program politically attractive, lowering resistance to the program and increasing the chances of implementation.

PACE programs also provide many benefits to the property owners to participate in the program. The main benefit of PACE is that it reduces, or nearly eliminates, the upfront cost of sustainable energy upgrades. These upfront costs are often a barrier to energy efficiency and renewable energy technology upgrades, even for a property owner who strongly desires the upgrade. PACE programs help reduce the barrier of insufficient access to capital for sustainable energy upgrades. One of the key features of PACE is a critical benefit to property owners: the fact that the loan transfers with the property when sold. This means that the property owner is not responsible for the loan payments after selling the property. Given the long pay-back period of many sustainable energy upgrades, property owners are hesitant to make a long-term investment (Speer 2010). PACE provides further incentive for investment in these upgrades by eliminating the need to stay with the property to achieve the full benefits of the upgrade.

Problems Facing PACE Programs

On July 6, 2010, the Federal Housing Finance Agency (FHFA) issued a statement that called for, "a pause in such [PACE] programs so concerns can be addressed" (Federal Housing Finance Agency 2010). The primary concerns are over the senior status of the lien placed on the property under a PACE program. The letter states: "First liens established by PACE loans are unlike routine tax assessments and pose unusual and difficult risk management challenges for lenders, servicers and mortgage securities investors" (Federal Housing Finance Agency 2010). In short, they challenged that PACE assessments are more like loans than traditional assessments, thus violating Uniform Securities Instruments, a the standard mortgage contract, which prohibits loans that have a senior lien priority to a mortgage (U.S. Department of Energy 2010). Further, the FHFA claims that these senior liens "disrupt a fragile housing finance market and long-standing lending priorities" (Federal Housing Finance Agency 2010).

The FHFA letter directed the Federal Home Loan Banks, Fannie Mae, and Freddie Mac, not to underwrite mortgages for properties with a PACE assessment. Fannie Mae and Freddie Mac play a major role in the secondary home mortgage market. They are charged with keeping money in the mortgage market by buying loans from commercial banks. They then "bundle the loans they buy into securities, which are sold, with a guarantee of payment, to investors worldwide" (Reuters 2008). As a result, Fannie Mae and Freddie Mac combined play a role in "nearly half of the entire U.S. mortgage market" (Reuters 2008). The FHFA statement directing Fannie and Freddie not to underwrite mortgages with PACE assessments has essentially put a majority of residential PACE programs, on hold for the time being.

Commercial PACE financing

The FHFA letter in July 6, 2010 dealt only with the home mortgage lending market and residential PACE programs, it did not directly address commercial PACE program (U.S. Department of Energy 2010). Therefore, while residential PACE programs have been put on hold, commercial PACE programs have been allowed to operate across the country. There are two reasons commercial programs are still viable, since the commercial mortgage market is distinct from the home mortgage market, Fannie Mae and Freddie Mac do not have the same role in the commercial mortgage market, and thus the FHFA statement does not impact commercial programs. Also, a key feature in all commercial PACE programs is the required consent of the mortgage holder before a PACE assessment can be placed on the property. This is because of a "Due on Encumbrance" clause in most commercial mortgages that "gives the mortgage-holder the right to call the loan due if additional debt is placed on the property without the lender's consent" (U.S. Department of Energy 2010). Even as a requirement, this serves to alleviate some of the security concerns stemming from the senior status of PACE liens.

Commercial PACE programs can be used to finance sustainable energy upgrades on a wide range of commercial properties. Eligible properties can include shopping malls, commercial office buildings, restaurants, apartment buildings, or any other commercial property. Due to the nature of commercial properties, commercial PACE programs tend to be larger than residential. In order to make a noticeable impact on a commercial building's energy use, a larger investment in energy efficiency or renewable energy technologies is needed. This drives up the amount of funding needed for a commercial PACE program to make a difference on a larger scale. In order to meet the level of funding required of a commercial program, there are three main types financing models: warehoused, pooled bonds, and owner arranged (Lawrence Berkeley National Lab 2011).

Under a warehoused financing model, the municipality takes out a large line of credit to provide loans for qualified projects on an as-needed basis. Once a sufficient amount of funding has been administered, the municipality can aggregate the portfolio of loans to be sold as a municipal bond issuance. This bond issuance can be used to either pay off the line of credit or replenish it for the next application cycle. In a pooled bond PACE program, the locality opens an application period. At the end of the application period, the locality will sell bonds to cover the cost of all approved upgrades. This can often result in a delay between application, approval, and receiving funding for property owners. A third financing model is called owner-arranged financing. In an owner-arranged PACE program, the property owners independently negotiate for a loan to cover the cost of the upgrades with a private bank. The owner would apply to locality with a program plan for the locality to place an assessment on the property. If approved, the owner would be able to leverage the security and enforceability of the lien to negotiate loan terms and secure financing. Once the funding has been received by the owner, the city transfers collection rights on the lien to the private bank (Lawrence Berkeley National Lab 2011). The owner-arranged financing model places the task of finding funding on the property owner, rather than with the city.

As of January 2011, there are six operational commercial PACE programs across the United States. These include programs in Fresno, Palm Desert, Placer County, and Sonoma County, California, as well as Boulder, Colorado and Annapolis, Maryland. Some commercial programs early on such as Palm Desert in 2008 and Sonoma County in 2009, while most other program have been implemented in the wake of the FHFA statement. Each of the currently operating programs differs on multiple aspects of the program. For example, the Boulder program focuses mainly on financing energy efficiency upgrades on properties, with an average project size of $51,000 and a max project size of $200,000. Boulder's program employs the pooled bond financing model with the primary source of funding coming from city issued bonds. The Sonoma County program on the other hand utilizes the warehoused financing model where county treasury funds are the primary source of funding. Sonoma County's commercial PACE program has approved $7.27 million in project funding as of January 2011. The program has a maximum project limit of $2.3 million and an average project size of $196,000 (Lawrence Berkeley National Lab 2011). The Annapolis PACE program began initially by utilizing funds from the American Recovery and Reinvestment Act (ARRA) of 2009 (City of Annapolis 2009).

There are also several programs that are currently in various stages of development. Programs in development include a state-wide program in California, a program incorporating 14 municipalities and the city of Cleveland in Ohio, a program developed by the Western Riverside Council of Governments (WRCOG) which consisting of 17 cities. There are also programs in development in the following cities: Ann Arbor, Michigan; Los Angeles, California; San Francisco, California; Santa Fe, New Mexico; and Washington, D.C. It should be noted that both Los Angeles and San Francisco will be piloting the owner-arranged financing model in their programs expected to roll out later in 2011 (Lawrence Berkeley National Lab 2011).

Harrisonburg Politics

One of the first steps in attempting to get a PACE program in Harrisonburg was to meet and discuss the idea with Kai Degner who is a current member of the city council. With the help of Ben Delp, a JMU Masters of Public Administration graduate who works with the Institute for Infrastructure and Information Assurance (IIIA) at James Madison University, I was able to secure a meeting with Kai Degner. One of the first subjects that came up in the initial meeting with Kai was the need to fully develop a comprehensive list of the benefits to the city. The benefit of promoting sustainable energy will not garner the support needed from members of the city council in Harrisonburg. It's not to say that the city council does not support sustainable energy, but the goal of sustainable energy must be accomplished in a way that city government would agree with. The types of arguments that would most effectively persuade members of the city government would an emphasis the economic and community resiliency benefits.

After the initial meeting, I continued to do research on the benefits to the city with a PACE program. I spoke with Dr. Nicholas Swartz in the Department of Public Administration at James Madison University and Cheryl Elliot of the Institute for Infrastructure and Information Assurance at JMU to get a better understanding of the potential benefits of a PACE program in Harrisonburg. In my meeting with Dr. Swartz, I was able to discuss with him further on what types of arguments would be effective. He reinforced the ideas of emphasizing the economic benefits in discussions with city officials. In my meeting with Cheryl Elliot, we discussed the community resilience implications of a PACE program. She helped me to develop a better understanding of the idea of community resilience. I was then able to meet with Kai again, this time Isaac Hull, a local mortgage specialist with an interest in PACE, was able to join the conversation as well. Isaac's presence at the meeting brought in the welcome perspective someone on the business side of the conversation.

I had originally wanted to implement a traditional, residential PACE program in Harrisonburg. There are many examples of successful residential PACE programs around the country which would allow Harrisonburg to potentially model a program after one of the many successful programs. However, with the FHFA statement it became clear that a traditional, residential PACE program was not the best way to move forward in Harrisonburg due to the high level of uncertainty of the future of residential PACE programs. It could be years, if ever, before residential PACE programs are sanctioned by the FHFA. It would not have been best to move forward with a policy that was not currently viable and might never become viable. Instead, I began to look into implementing a commercial PACE program in Harrisonburg. Initially, I looked into a more traditional commercial program, similar to the residential program where the city would loan the money, collect the payments, and issue bonds to cover the loans.

Discussing the idea of a traditional, warehoused or pooled bond, commercial program with Degner and Hull brought up the concerns about the city's ability and willingness to raise the necessary funds. A successful commercial program would require even more initial funding than a residential program because of the large nature of the potential projects. This would require even further administrative work by the city to secure the large amount of funding. There was also a general concern of using city money to finance a PACE program. While theoretically the city would be able to recoup the money loaned, through regular payments or by enforcing the lien in the event of default, there were still lingering concerns over financing the program using city bonds. There were also questions about the city's capabilities to raise the type of money that would be needed to fund a successful PACE program, especially in the current economic environment. This city would only have limited ability to raise the necessary funds for a traditional PACE program due to an established debt cap that the city cannot legally exceed. Raising this debt cap is essentially out of the question as such action would not gain the support needed to pass the city council. There was a strong desire to find the best way to leverage private funding for a PACE program. Doing so would increase the likelihood of public and political support within the city for a PACE program.

After speaking with Degner and Hull, I continued research into potential commercial PACE programs. I was looking to find a program what would alleviate some of the initial concerns related to the use of city funds. That is when I came across the idea of using an owner-arranged financing model for a commercial PACE program. I first read about owner-arranged financing in a briefing paper from the Institute for Building Efficiency titled *Unlocking the Building Retrofit Market: Commercial PACE Financing, A Guide for Policymakers.* Under an owner-arranged model, property owners would arrange the financing with a private bank on their own. The city's role is to place a lien on the property for the amount of the loan. The property owner can leverage the added security of the lien to secure a loan for the clean energy upgrade. Before pursuing an owner-arranged commercial PACE program further, I wanted to ensure that it would be allowed under the Virginia enabling legislation. To ensure that it would be legal, I emailed Patrick Cushing to get his legal opinion on an owner-arranged PACE program. In a email message to the me on February 14, 2011, Patrick stated: "In summary, I think by taking Subsections D and C together there is enough detail and intent for a locality to establish an ordinance that would authorize the use of private lenders for the loan that is secured by the lien enforceable by the locality." He also noted that nothing in the enabling legislation limited PACE programs to residential programs so a commercial program could be viable.

In traditional programs, a commercial owner would hire a contractor to perform an energy audit. The results of the energy audit would help the owner determine the type and size of the clean energy system they should install on their property. Once a plan for the upgrade has been established, the property owner applies to the PACE program with the city. Also, as in any commercial program, the property owner would have to provide the city with the consent of the mortgage holder during the application before the lien can be placed on the property. If the city approves of the upgrade plan, the city will agree to place a lien on the property. The owner is then able to negotiate the terms of the loan with a commercial lender with the security of the lien. The city then transfers the assessment collection rights to the private lender and the property owner makes the payments to the private lender. One of the main benefits of an owner-arranged PACE program versus a more traditional program, such as the pooled bond or warehoused financing models, it the fact that the city is not responsible for any aspect of the financing. The city does not have to issue bonds, or ensure payment on the bonds. The city does not have to used time and resources to secure the financing for the program, as that responsibility in on the property owner. As in a traditional PACE program, under a owner-arranged program the lien would transfer with ownership of the property in the event of a sale.

While a traditional PACE program is very secure, an owner-arranged program eliminates any risk to the city. With a traditional program, the city would still be limited by the debt cap, until such a time that they were able to bundle and sell the loans to a private lender. Under an owner-arranged program no taxpayer dollars are used in the program. An owner-arranged program also cuts down on administrative cost incurred by the city, which can be covered by an application fee for the program. The city already has the people and mechanisms in place to operate an owner-arranged PACE program. In the event of a default, the city already has the staff in procedures in place to execute a sale of the property to pay off the lien on the property. Another key benefit of an owner-arranged program is that it is able to leverage private capital and promote private investment in the sustainable energy market, with only minor additional work on the city's part. Essentially, by passing an owner-arranged program the city is publicly supporting sustainable energy. By approving a project and placing the lien, the city is, in a sense, applying a "seal of approval" on the project. The lien on the property supports and assists the owner with securing funding and negotiating more desirable terms on the financing.

My next meeting involved several members of the city government, including the city attorney, the assistant city manager, and the director of economic development for Harrisonburg. For the most part, they seemed to understand the mechanisms behind PACE and owner-arranged PACE and they seemed to be generally supportive of the idea. They brought up the idea of potentially reaching out to local banks to determine which banks may be interested in participating in a PACE program. The city could then keep a list of interested lenders to assist property owners in securing financing. It would be an informal level of interest and all banks would be allowed to request to be included in the list. There was also discussion on the ramifications on implementing a PACE program as well as the local property tax exemption for solar. There were questions on the ramifications of the city providing a double incentive for solar through the exemption and the PACE program. This was a minor concern and we agreed that the two programs are not creating the same incentive. Also, a double incentive of solar project is not really a bad consequence of implementing both policies. A double incentive would only help to increase the investment in solar technologies in Harrisonburg.

The city attorney asked about difference between the city placing a lien on the property and the bank taking out a deed of trust on the property. After looking into the issue, I learned that a deed of trust must be resolved prior to the sale of a property. Also, the administrative cost and process for collecting on a deed of trust then fall with the trustee, whereas with the lien the collection procedure is the responsibility of the city. This then led to the concern over responsibilities of the city government in the event of a default. There were concerns over the public perception of using city resources to execute a sale of the property to collect money for a private bank. The question being, should the city be getting involved in the collection of loans for private lenders? There was further discussion on the topic at the meeting. Both Kai and I theorized that the likelihood of a property owner defaulting on only the PACE loan was relatively low. First of all, if the system in designed properly the owner should be saving money on their energy cost, which could then be used to cover the loan payments. The city can design the program criteria to help ensure savings. Also, if an owner is in default on the PACE loan, they are likely in default on their local taxes. This that event, the city is already obligated to execute a tax sale on the property to collect on the delinquent takes. To collect on the PACE lien as well would only require minor additional effort on the part of the city attorney responsible for processing the tax sale.

The next step in the process was to gain the support of members of the city council. Kai felt that, ultimately, an in-depth review of PACE financing by the city staff would be needed to move forward. A council vote is necessary to authorize the city staff to perform the review. The best course of action was to gain the support of the council to authorize the city staff to complete an in-depth review of PACE financing. The objective was to meet with members of the city council to introduce PACE, educate them on the benefits, and to gain their support for the policy. I wanted to gain the support of at least three members of the city council. This would constitute a majority of the city council needed to approve a review of PACE financing.

With Kai's assistance, I was able to arrange a meeting with the current mayor of Harrisonburg, Richard Baugh. As a practicing lawyer involved in real estate, Mayor Baugh was familiar with the mechanisms behind PACE financing, but he was not familiar with PACE financing itself. He seemed generally supportive of the idea of PACE financing. Upon learning of the requirement of mortgage holder consent, he became unsure of a commercial bank's willingness to allow a senior PACE lien on the property. However, further research shows that all operating commercial PACE programs have that requirement. It shows that while some banks might be hesitant to allow a PACE lien, other banks are willing to allow the PACE lien on the property. Mayor Baugh also brought up a concern with the wording of the enabling legislation. His concern was that he didn't see where in the enabling legislation the city would be allowed to place a senior status lien to secure the loan. He acknowledged that the enabling legislation allowed for liens to be placed on the property and collection rights of the lien to be transferrable. His concern would be if the program was implemented, the possible ramifications of a judge ruled that the city did not have the right to place a senior status lien on the property. I am currently performing further research into the issue. I have been in contact again with Patrick and he has recommended a few other people to discuss the concern with. He also suggested that if this issue becomes a sticking point for implementing a PACE program in Harrisonburg, than it might be prudent to suggest amending the state code to provide further clarity on the subject.

Potential Impact

I feel that a PACE program has a real chance of actually getting implemented in Harrisonburg. Once implemented, I feel that this policy has the potential to have a lasting and significant impact on promoting sustainable energy Harrisonburg. PACE has the potential to have a significant impact because it helps to change the underlying economics of decision making when it comes to energy efficiency and clean energy upgrades. With an owner-arranged PACE program, the only long-term limitation on the amount of financing is the availability of private capital. The program is not reliant on a limited amount of government funding or on one-time grants such as those distributed under the Recovery Act of 2009. Without utilizing government funding, the program cannot be cut in a budget balancing move, as we have seen with other programs in the current economic situation.

With a PACE program, Harrisonburg could see a boom in the local "clean technology" or "green" economy. A PACE program would provide a new wave of "green collar" local jobs. Related job categories include construction, contracting, and energy consulting. As the first locality in Virginia to implement a program, Harrisonburg could serve as a leader in the emerging "green" economy in both the Shenandoah Valley and Virginia. This would enable Harrisonburg to get in on the ground level of this emerging industry, which is considered by many as a prime area for growth as we move into the future. Harrisonburg could also garner national recognition as one of the first few PACE programs in the country. Harrisonburg, Virginia would be listed in all of the briefing papers and PACE status updates published by the DOE and its national labs.

Harrisonburg could also see job growth across several sectors of the local economy, both related and unrelated to the energy industry. For example, as the first program in the Valley, energy contractors and equipment installers and manufactures would be drawn into Harrisonburg. As other programs are implemented in the Valley, Harrisonburg companies would grow and emerge as leaders in the PACE upgrade market. A commercial PACE program would also serve as an incentive to sustainability minded companies to relocate to or remain in Harrisonburg. As public perception shifts, an increasing number of companies will strive to be more sustainable. This public and corporate mindset is already beginning to shift towards a focus on sustainability. By implementing one of the first programs, Harrisonburg will be able to reap the benefits of this shift towards sustainability.

Prospects

I am currently in discussion with members of the Harrisonburg city government on moving forward with commercial owner-arranged PACE. These discussions include meetings with members of the city council to explain PACE financing and to gain their support for a program in Harrisonburg. I have also set meetings with members of the city staff to get their input on what needs to be done to implement a viable PACE program in Harrisonburg. I will also be working on drafting legislation to present to members of the city council.

There is a strong chance that a PACE program will be implemented in Harrisonburg. PACE financing has received positive responses from industry stakeholders, Harrisonburg residents, and members of the city government. People seem to realize that potential benefits and impacts of a PACE program. I have not personally encountered any strong resistance or aversions in my discussions with various members of the Harrisonburg community. I feel that the support exists in Harrisonburg for a PACE program. The key to implementation will be to leverage this support and continue to campaign for a PACE program. Support from members of the local community, including local banks and small business willing to take advantage of a PACE program, could convince the Council to implement a PACE program.

Across Virginia

One of the goals of this project was to help Harrisonburg become a leader in sustainable energy in the Shenandoah Valley and Virginia. The hope is that other localities throughout the Commonwealth will be able to emulate Harrisonburg in implementing their own PACE programs. For the most part, the steps taken in Harrisonburg can be transferred and used in other localities.

Private citizens or other organizations interested in PACE across Virginia should start by identifying a local public official that may be interested in supporting a program. The next step should be to meet with the official and discuss the idea of implementing a PACE program in the area. Hopefully, the official will be able to shed light on the intricacies of politics in the area and advise on the best approach for moving forward. Concurrently, it is beneficial to begin spreading the word on PACE financing in the area. This should include meetings and discussions with the general population as well as potential stakeholders, including business owners, builders/architects, green tech companies, and local banking leaders. This will provide insight on potential concerns as well as help to identify the areas of need within the community as they relate to clean energy.

Next Steps in Harrisonburg

The next step to implementing a PACE program in Harrisonburg is to continue to gain the support from within the city government. It would also be beneficial to continue to raise support for a program in the community. Most people that I have spoke with support PACE and are interested in learning more about it. Gaining additional support from people in the community has two main benefits. First, showing community support for a program will only help to gain further support with members of the city government. Second, initial supporters, such as local businesses, of a PACE program could potentially form the initial round of applicants. Additionally, public support for a PACE program will aide in future marketing of the program. Further support could be gained by including banks and local construction, consulting, and architecture companies in discussions about PACE in Harrisonburg. The inclusion of local banks will be a key aspect of implementing a PACE program. It will serve as an opportunity to educate local bankers on the concept of PACE financing. Also, it is an opportunity determine if local banks would be interested in participating in a PACE program.

Once the support for the program exists, the next step is to get the issue on the city council's agenda. Getting PACE on the Council's agenda could take a few different forms. One possibility is to have the Council pass a resolution supporting PACE financing and authorizing further research into the policy by the city staff. This was the method pursued in the creation of the Berkeley, CA program. Its city council initially passed a resolution approving of the concept of PACE financing. This allowed the city staff to work on designing their pilot program and to determine the scope and details of the program. This also allowed the city to perform various financial impact analyses of the proposed PACE program. Over the course of a year, the city council passed ordinances that approved the concept, established the financing district, amending the tax code to allow for PACE, scheduled a public hearing on the program, and approved the sale of bonds to launch the pilot program (Office of Energy and Sustainable Development 2010).

Alternatively, a draft ordinance could be created with help from people within the city and presented to the city council, with the help of Kai Degner. This more direct method would require more upfront effort before taking it to the city council. The best approach may be to draft an ordinance approving of a PACE program and establishing a person or group of people within the city charged with the responsibility creating and designing the Harrisonburg PACE program. Once the program guidelines have been created, they could be presented to the City Council for final approval and implementation.

Program Considerations

There are many decisions that need to be considered when it comes to establishing a PACE program. The main decisions are the areas of program guidelines, requirements, administration. One of the first decisions is to determine the scope of the program. This includes how much funding will be approved, either on yearly basis or per application cycle.

The program should also include a loan floor and ceiling values for projects under the program. The loan floor helps to promote large-scale and large impact projects, rather than just simple upgrade that may not need the program as an incentive. The ceiling helps to limit the risk to the city for individual projects. Also, program eligibility requirements will need to be set. The types of commercial properties eligible for the PACE program would need to be discussed. Below is a suggested set of PACE commercial underwriting/program eligibility criteria from the Department of Energy's *Clean Energy Finance Guide*:

- Applicant(s) has/have clear title to the property.
- The property is located within the energy financing district.
- All legal owners must agree to participate and sign the application.
- Applicant has written existing-lender (mortgage-holder) consent.
- A maximum Lien to Value (LTV) ratio (i.e., what percentage the PACE financing will be compared to the property value) is generally capped at 10%.
- Applicant has no recent notices of default or foreclosure.
- Applicant has no recent bankruptcies.
- Applicant is current on mortgage payments.
- There is a limit on involuntary liens (e.g., liens placed by contractors who were not paid for their work) on the property.
- Details about current occupancy of the property are supplied (U.S. Department of Energy 2010).

These criteria are not intended to be an all inclusive list. Many of the suggested requirements are influenced by the DOE's PACE best practice guidelines published May 7, 2010 in its *Guidelines for Pilot PACE Financing Programs*. Also, the criteria are influenced by the requirements that banks typically request the property owner meet to ensure the security of the loan.

One of the main considerations in creating a PACE program will be determining the qualifying upgrades. The determination must also be made as to whether qualifying upgrades will be limited to a list determined by the city. For example, the city could determine a list of qualifying upgrades, and only the upgrades on the list will be considered under the PACE program. This helps to simplify the application and approval process, but it can limit the potential impact of the program. Another option would be to provide a list of prequalifying upgrades, but accept proposals for other clean energy and energy efficiency upgrades for approval on a case by case basis. This allows for program flexibility and can help to fully realize the potential impact of a PACE program. In either case, the city should strive to approve technologies best suited to the local community.

The city must also decide on how the program will be administered. This will include the application and approval process, the legal process of placing the assessment, and the responsibility for the enforcement of the lien. Program administration can, to a certain extent, be handled by a third-party contractor, if so desired. For example, the application and approval process can be handled by a private company. This contractor can also be responsible for a potential program website to aid in the application process. Additionally, the private company could also be responsible for helping to market the program. These tasks can also handled "in house" by the city itself. The responsibility of placing and enforcing the lien on the property should be given to those within the city already responsible for those processes. One of the benefits of implementing an owner-arranged PACE program is that the additional administrative burden to the city is less than would be required by traditional PACE programs.

Future Recommendations

I recommend that Harrisonburg start its PACE program as a pilot program that would start small and have the potential to grow into a full-fledged program within a few years. The city could open with the initial round of applications with the goal of approving a small number or small amount of approved funding. This will give the city the opportunity to test the program and work out potential unforeseen issues. Initially, I suggest limiting the qualifying upgrades to a short list of select technologies with proven track records of savings in the area. However, as the program increases in size and scope, I recommend that the list of qualifying upgrades be expanded, including the opportunity to review non-prequalifying technologies on a case by case basis. I believe that the city has the capabilities to handle the administration of the initial pilot program. It may be beneficial to look to other programs or a private company when creating the application and application process. I would review publications from the Department of Energy and other organizations, as well as other active programs, in determining the program eligibility requirements. I would also suggest speaking with bankers to determine any additional requirements that would encourage bank participation in the program. The program and the community would benefit if local banks were to participate in the program.

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Appendix A: Virginia Enabling Legislation

§ 15.2-958.3. Financing clean energy programs.
A. Any locality may, by ordinance, authorize contracts to provide loans for the initial acquisition and installation of clean energy improvements with free and willing property owners of both existing properties and new construction. Such an ordinance shall include but not be limited to the following:

1. The kinds of distributed generation renewable energy sources or energy efficiency improvements for which loans may be offered;

2. The proposed arrangement for such loan program, including (i) a statement concerning the source of funding that will be used to pay for work performed pursuant to the contracts; (ii) the interest rate and time period during which contracting property owners would repay the loan; and (iii) the method of apportioning all or any portion of the costs incidental to financing, administration, and collection of the arrangement among the consenting property owners and the locality;

3. A minimum and maximum aggregate dollar amount which may be financed;

4. A method for setting requests from property owners for financing in priority order in the event that requests appear likely to exceed the authorization amount of the loan program. Priority shall be given to those requests from property owners who meet established income or assessed property value eligibility requirements;

5. Identification of a local official authorized to enter into contracts on behalf of the locality; and

6. A draft contract specifying the terms and conditions proposed by the locality.

B. The locality may combine the loan payments required by the contracts with billings for water or sewer charges, real property tax assessments, or other billings; in such cases, the locality may establish the order in which loan payments will be applied to the different charges. The locality may not combine its billings for loan payments required by a contract authorized pursuant to this section with billings of another locality or political subdivision, including an authority operating pursuant to Chapter 51 (§ 15.2-5100 et seq.), unless such locality or political subdivision has given its consent by duly adopted resolution or ordinance.

C. The locality shall offer private lending institutions the opportunity to participate in local loan programs established pursuant to this section.

D. In order to secure the loan authorized pursuant to this section, the locality shall be authorized to place a lien equal in value to the loan against any property where such clean energy systems are being installed. The locality may bundle or package said loans for transfer to private lenders in such a manner that would allow the liens to remain in full force to secure the loans.

E. Prior to the enactment of an ordinance pursuant to this section, a public hearing shall be held at which interested persons may object to or inquire about the proposed loan program or any of its particulars. The public hearing shall be advertised once a week for two successive weeks in a newspaper of general circulation in the locality.
(2009, c. 773; 2010, c. 141.)

Appendix B: Overview of Steps to Launch Commercial PACE

From the Department of Energy's *Clean Energy Finance Guide,* the following presents the key steps that local governments may follow to implement a commercial PACE program:

1. Review and Address Issues: Become familiar with issues related to PACE and factor their impact into program design and implementation.

2. Establish Supporting Framework: Lay a solid foundation for the program in the areas of team composition, goals, legislation, and assessment district formation.

3. Choose Capital Sourcing Approach(es): Choose how the financing will be funded.

4. Choose Credit Enhancement and Apply the American Recovery and Reinvestment Act of 2009 (ARRA) Funds: Decide how to achieve the best interest rates for the program and how best to apply and leverage ARRA funds to fit the program's design.

5. Choose Eligible Property Types: Select the commercial property types eligible for the program.

6. Assemble Eligible Project Measures: Draw up a list of project measures eligible for PACE financing.

7. Choose Energy Audit Requirements: Decide the types of energy audits applicants will be required to undergo to assess expected project energy/cost savings.

8. Choose Program Eligibility Criteria: Determine the program underwriting/eligibility criteria that applicants and their properties must meet.

9. Leverage Existing Utility Rebate/Incentive Programs: Investigate local utility rebate/incentive programs and how best to leverage them.

10. Plan Quality Assurance/Quality Control: Decide how the program will ensure that project work meets program quality standards and how to guard against fraud.

11. Design Application Processing Procedures: Design the process for reviewing applications and either approving or rejecting them.

12. Specify Contractor Requirements: Specify the requirements for energy auditors and contractors to participate in the program.

13. Market and Launch Program: Decide what kind of outreach will be made to property owners and contractors and launch the program.

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Reducing the Cost of Biodiesel Production in the Shenandoah Valley

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ABSTRACT

Biodiesel is a clean-burning, renewable fuel with significant potential for the Shenandoah Valley. It can be made from a wide variety of naturally occurring vegetable oils and can also be produced from purified waste cooking oil. Currently, there are three small-scale biodiesel startup companies that are hoping to produce biodiesel from locally-grown agricultural products and regionally supplied waste-cooking oils. One challenge for these startup companies is producing biodiesel that meets or exceeds the ASTM specifications for Biodiesel. The purpose of this project was to establish Gas Chromatography (GC) analysis according to the ASTM specifications and to apply the analysis in support these 3 local-area biodiesel startup operations. To do this, a Hewlitt-Packard 5890 GC was outfitted with an Agilent CP9078 column for biodiesel analysis. Standard calibrations curves were prepared in accordance with the ASTM D8635 Standard for Free and Total Glycerol Content. R-squared values were determined to be 0.98, 0.98, 0.93, and 0.95 for glycerol, monoolein, diolein, and trioolein, respectively, indicating that the system is calibrated and functioning properly. These reference curves can now be applied to determining the overall quality of biodiesel, enabling JMU to provide a less-expensive fuel quality analysis to local-area producers during the startup phase of operation when a high-level of adjustments and calibrations are anticipated. In addition, in-house GC analysis will also support research at JMU into solid-phase biodiesel catalysts and non-conventional production strategies aimed at reducing production costs. In order to decrease the cost of the filtration process, a PVC column was built and filled with locally cut woodchips, which were obtained free of charge. The raw biodiesel was ran through the and compared to an unfiltered sample. The results showed a 45% decrease in glycerin, 20% in monoolein, 7% in diolein, and 10% in trilolein. While these results are only preliminary, they show promise.

Background

The Shenandoah Valley is one of the most agriculturally rich areas in Virginia, making it an ideal area to integrate renewable alternative fuel production within an established agricultural community, creating a sustainable fuel market for the benefit of farmers. In order to conceptualize this potential system, three start-up companies in the biodiesel production industry were visited.

Fox Run Farms

The first biodiesel producer that was visited in the Shenandoah Valley was Ian Heatwole's plant at Fox Run Farms, which is still in the process of being completed and obtaining all of the necessary legal permitting. For years, the local farmers had to ship all of their crops to Norfolk, VA in order to have them roasted or pressed. The cost per bushel has continued to increase, which eventually led Ian to open his open roasting facility here in Harrisonburg. This has been up and running for several years, and in the last five years, he has decided to start pressing the seeds, generally soy, and using the oils from that to produce biodiesel which will be sold back to the farmers.

While this is a great idea, keeping all of the crops local and helping one another out, Ian has run into several permitting issues here in Rockingham County. After three years of appeals and applications, he is nearing completing of the process and is hoping to be up and running in the near future. In 2011, he purchased a full reactor from California that was producing ASTM quality fuel at that site, but has yet to be tested at Fox Run Farms. Ian was the first person to introduce the idea of using woodchips as a glycerin filter instead of the pricey ion exchange resin, leading us further research possibilities.

Shenandoah Agriculture Products

Shenandoah Ag. is a plant that has recently been opened outside of Winchester, VA. This is a relatively small plant, who uses their own canola oil to produce biodiesel which is sold for local farm use. The canola seed are mechanically crushed and then filtered to produce a totally natural food grade canola oil (Shenandoah Ag. Prodcuts FB)

This plant was designed and built by Josh Leidhecker, who owns a farm in Pennsylvania. His original design was to make the entire plant mobile, having in built almost entirely inside of an 18-wheeler tractor trailer. After having this done, the owners of Shenandoah Ag. decided to have a building built for the plant. The majority of the production is still done inside the trailer, with a small office and some storage and filtration systems in the attached garage.

On top of using their own canola oil, they are also using waste vegetable oil (WVO) from local businesses who believe in this full circle system that starts with the farmers and ends back in their hands. While they are still very young, this is starting to exemplify that biodiesel can be successful on a smaller, local scale.

Wholesome Energy

Wholesome Energy is the third biodiesel producer that we have visited and plan to potentially work with in the near future. Like Shenandoah Ag, they too are a new plant that is just months away from starting full scale production. Wholesome Energy is a side project of Wes and Nathan Pence. The two brothers, along with their father, own a number of different businesses all operating under the same roof.

They started with a food company, later opening a trucking company to help distribute their goods. On top of those, they also own a water bottle labeling and distribution company who has won awards from having Virginia's best water. About four years ago, they decided to try the local small scale biodiesel model seen around the Valley, which would help power their trucking company as well as local farm vehicles.

It has taken Wholesome Energy a little over three years to build their facility, mainly because they have so many other responsibilities and previous arrangements that it wasn't a priority to get the plant fully functioning immediately. The benefit they have seen from doing this over time, and being able to salvage tanks and parts, is that they have fully paid for the plant and are in no debt. As of October 2012, the only thing left before starting operations is to complete the automation system they had designed, and get their final permits and legal matters completed, which is estimated to be done by November or December.

Since they have not produces fuel yet, they do not have ASTM certification for their plant or fuel. They have requested that we do some preliminary tests using our gas chromatograph to check the free and total glycerin levels before they submit it and spend several thousand dollars to an ASTM partnered laboratory. We have also offered to help them on their startup in any way possible.

Until the plant is fully functioning, Wholesome Energy has currently been collecting and selling WVO to other producers around the southeast. In preparation for their plant opening, they have initiated a WVO collection system with local restaurants where they are provided a bucket to store their used oil in, then Wholesome will have them picked up and replaced when they are full, providing a free oil feedstock.

Issue Proposed

Two issues will be addressed in order to assist these start-up companies in their efforts to economically produce biodiesel. First, establishment of Gas Chromatograph operational procedures will be undertaken, followed by consistent and accurate execution of ASTM D 6584 Standard for Free and Total Glycerin protocol. This instrumental analysis gives the companies an opportunity to gain a perspective on the quality of their biodiesel prior to submission to a standards testing company. In addition to discovering fuel quality, the test also gives insight into parameters of the production process that may need modification to improve the final product. Secondly, in order to reduce the costs of production, and ultimately of the final product, investigation into the purification process of crude biodiesel will be pursued. Ion exchange resins are commonly used in place of water washing to remove impurities from crude biodiesel, but must be washed or replaced once they have become saturated. Woodchips will be examined as a possible pretreatment option to extend the lifetime use of ion exchange resin. Various types of wood will be studied and compared between themselves and against ion exchange resin to determine functionality as a purification treatment. Feasibility of using spent woodchips as a fuel source will be verified by pressing the woodchips into a pellet for use as a fire starter. The heat content of the pellets will be measured using a bomb-calorimeter. All experimental tests will be conducted with n=7-10 along with statistical analysis to determine significance of results. A lifetime cost analysis will be calculated for the use of resin, woodchips, and resin/woodchips combination with consideration of waste disposal.

Introduction

The transportation sector of the U.S. is a critical component of the country's infrastructure. In addition to transporting raw materials and finished products persons rely on vehicle to travel to areas of employment. It can be surmised that without the level of transportation currently in place, commerce within the U.S. and the world at large would not exist as it does today. As of 2010, proved oil reserves under the control of the U.S. are around 23.267 billion barrels (EIA) while consuming 6.9165 billion barrels in 2011 (EIA). These two figures show that consumption of solely U.S. petroleum would not last more than four years. Subsequently, the U.S. is a major importer of foreign petroleum. Demand for petroleum oil continues to increase from year to year, increasing the dependency of the U.S. on foreign suppliers.

In an effort to relieve a portion of U.S. dependency, several alternative sources of fuel have been researched and investigated for potential to be integrated into the current fuel infrastructure. One particular fuel of focus in this area is biodiesel. Like other biofuels, biodiesel is derived from natural sources such as seeds, nuts, and fruits, but displays particular advantages of application. Refined biodiesel exhibits fluid characteristics similar to that of petroleum diesel in diesel combustion engines meaning that unlike ethanol, continued use of biodiesel, either blended with or in place of petroleum diesel, does not result in engine damage. This quality makes biodiesel an easy substitute for integration into the current fuel infrastructure. Another advantage is the relatively simple production process compared to petroleum diesel allowing fuel to be produced locally within the area where it will be put into use. Additionally, the production facility can be located in close proximity to the site of the feedstock, reducing transportation costs. The major advantage of producing biodiesel locally is the reduction of dependence on foreign oil imports. While domestic biodiesel production reduces the amount spent on foreign imports, it also fosters economic growth within the country as a growing business.

Biodiesel is primarily produced from the natural oils derived from agricultural products such as soybean, canola, and groundnut. Thus, areas invested in agriculture provide the ideal locations for biodiesel production. One region in particular that could incorporate biodiesel production with future benefits is the Shenandoah Valley. The Shenandoah Valley is one of the top? agricultural regions in the state of Virginia. Integration of biodiesel production infrastructure within the region provides an opportunity for the produced goods to find a local market for use. The biodiesel produced can be made available for use in the Shenandoah Valley, keeping the economy local and creating a sustainable system of supply and demand.

Despite the advantages of biodiesel as a solution to foreign petroleum dependence, there exists various problems associated with its integration into the current fuel infrastructure. The current cost of biodiesel is more than that of petroleum diesel per gallon by less than $1.00 but more than 50¢. This price difference is related to the cost of various aspects of the biodiesel production process. The majority of the final product cost is due to the feedstock. Refined vegetable oil is primarily used in the food industry as cooking oil. This creates a high market price for purchase which translates into the cost of the biodiesel product. Other areas of significant cost in the production process are refining and purification. This study aims to lower the overall cost of biodiesel production by reducing costs associated with the refining of crude biodiesel. Woodchips are selected as a candidate to increase the longevity of ion exchange resin, a commonly used filtration mechanism in the refining stage of production. Ion exchange resins (IER) remove impurities such as glycerin, soaps, methanol, and catalyst, but eventually must be disposed of or recharged for further use. A comparison is made between the effectiveness of IER and woodchips in removal of impurities in addition to comparison between different types of woodchips. Functionality of woodchips as a fuel source is examined through pressing spent woodchips into pellets, followed by measurement of heat content using a bomb-calorimeter.

The following sections list the materials used and describe the methodologies followed to conduct experiments, display the observed and collected data, explain the significance of data with analysis and statistics, and provide conclusions implicated by results with suggestions for future areas of study.

Materials

The objective of this experiment is to assist local biodiesel producers by testing In order to properly and safely complete the experiment at hand, the following materials were needed:

Standards

- 500 mg monolein
- 50 mg Diolein
- 1 gram Triolein
- Internal Standard 1(Butanetriol Solution)
- Internal Standard 2 (Tricaprin Solution)
- Glycerin

Reagents

- Pyridine
- MSTFA
- n-Heptane

Glassware

- 4- 10 mL flat based Erlenmeyer flasks
- 1- 25 mL flat based Erlenmeyer flasks
- 1- 50 flat based Erlenmeyer flasks
- 7 – 2 mL vials with septa lids
- Crimper to fasten lids
- 2- 1 L beakers

Measurement Instruments

- Pipettes
- Glass 10 μL micro-syringes
- 250 μL syringe
- Mettler Toledo AG245 balance (d=.01 mg)

Safety Equipment

- Goggles/ eye protection
- Neoprene gloves
- Fume hood

Gas Chromatograph and Accessories

- HP 5890 Series II Gas Chromatograph
- GC Capillary Columns "Select Biodiesel for Glycerides 15 m +RG"
- Spare inlet septas
- Parts pieces

Wood Chips vs. Resin

- Wood chips or shavings from lumber yard
- B100 Biodiesel
- Dirty biodiesel
- Ion exchange resin
- 10' PVC piping and multiple fittings
- 5"x5" sheet of expanded metal
- Hose clamp(s)
- Two screen filters

Methodology

The gas chromatograph is the backbone of this research and was salvaged from the Chemistry Department last year. The students who worked doing similar research last fall were tasked with rebuilding it and getting it into working condition. Bernard Newman, a Chemistry major who graduated in May of 2012, did most of the work and showed us the basics about the machine and how to use it. There are still some small changes and fine tuning that needs to be done, but it is functioning well.

Several weeks were spent making sure we had the proper materials and safety equipment to perform any trials with the gas chromatograph. All of the standards and reagents were purchased by last year's biodiesel team and were located in the refrigerator in the lab. All of the measuring devices and safety equipment used was found in ISAT Lab 234/240 where the gas chromatograph is located. We did go to the Nursing Department looking for larger syringes, but they didn't have what we were seeking, so we used what we already had. The glassware was borrowed from the Chemistry Department. We didn't have the 10 mL Erlenmeyer flasks required for the ASTM testing in the lab and decided to stay consistent and borrowed all of the glassware (the styles were different between what was already available and what was borrowed).

On top of having all the safety equipment, we had to educate ourselves on the chemicals being used and their hazards. Pyridine and MSTFA are two of the chemicals used during the ASTM testing and are very dangerous. We called Sigma Aldrich numerous times to ask them about precautionary steps involving handling and storing these chemicals. We also spoke with Debbie Mohler, an Organic Chemist in JMU's Chemistry Department, about these chemicals and any safety concerns that should be taken.

For the calibration standards, guidelines were followed from the ASTM 6584 protocol with some exceptions. It called for 10 mL vials with sealed septa. In the lab, there were only 2 mL vials available, so all of the quantities for the standard solutions were scaled down by a factor of five (5) to adapt to this limitation. The stock solutions, which are the components that make up the standards, were the same quantities as called for in the protocol, both in mass and volume. All of this was done under a fume hood with proper eye protection and neoprene gloves, as recommended by Sigma Aldrich.

The next step is to create calibration curves for each of the five standard components: monoolien, diolein, triolein, butantroil, tricaprin, and butanetriol. This are graphed on Microsoft Excel, with concentration (ng/mL) as the x-axis and area percentage as the y-axis. If the R^2 value is in the upper 90% (as close to 1.00 as possible), than the equipment and standards are running appropriately and the next step may be taken. If not, the GC needs to be calibrate or tweaked in order to get reliable results. With these results, the retention times for each component found in biodiesel has been determined, allowing for the peaks and amounts in unknown samples to be calculated.

Now that a known sample has been ran and compared, the system is ready to run an unknown sample of biodiesel. The preparation for this is similar to the standards, but several different steps had to be taken before being inserting in to the GC. This procedure, like before, is from the ASTM 6584 protocol, but was adapted to fit into the 2 mL septa vials. Internal standards 1 and 2 (tricaprin and butanetriol) were added for identification peaks along with N-Heptane and MSTFA. A 1 μL sample is then inject into the GC and processed using ChemStation. It will take time to be able to interpret these results. Compared to the pure standard samples, the biodiesel has many impurities and has much more sporadic peaks.

The main research of this experiment was to explore different filtration options during biodiesel production. The plan is to compare the use of wood chips versus ion exchange resin that is currently being used. Ion exchange resin is the current popular choice in larger scale facilities, but is a large cost at about $6 per pound. If woodchips show to be successful, they could either replace the resin, or be used as a pre-filter to increase the lifespan of the resin.

In order to test this, a system needs to be built that can hold and transport biodiesel through a long tube of wood chips, and a separate system for the resin. As an initial design, a 40" piece of PVC tubing will be made with two screen filters at the bottom to catch any dust or falling pieces. The dirty biodiesel will be poured from the top and caught in a glass beaker once it is passed through the column and screen filters. Once this has been done for both a raw sample (without using any filter) and one filtered with the wood chips, they will tested using the GC and compared. In order for these results to show any statistical significance, a minimum of ten trials must be performed, in order to minimize the standard deviations and increase the precision. Each trial takes roughly 45 minutes, so this must be planned and scheduled in order to be completed in the allotted time frame.

Other tests that are going to be ran include testing different types of wood chips (i.e. hard vs. soft, red vs. white, etc.) to see if any are significantly more successful in filtering free and total glycerine, as well as soaps. After determining the best design and wood type, a cost analysis will be performed to determine the financial benefits associated with using wood chips in the filtration process at a medium size production facility.

Results

Calibration Curves

Due to the volume of available septa vials, the volumes of standards described in the ASTM D 6485 protocol were scaled down by a factor of five. The adjusted volumes for the standard solutions are shown in Table 1.

Table 1. Adjusted Volumes for Standard Solution Preparation. The initial volumes stock solutions to be included in the standard solutions were scaled down by a factor of five to accommodate a 2 mL septa vial.

Standard Solutions					
Standard Solution #	**1**	**2**	**3**	**4**	**5**
µL of glycerin SS	2	6	10	14	20
µL of monoolein SS	4	10	20	30	40
µL of diolein SS	2	4	8	14	20
µL of triolein SS	2	4	8	14	20
µL of butanetriol SS	20	20	20	20	20
µL of tricaprin SS	20	20	20	20	20
Heptane	1600	1600	1600	1600	1600
MSTFA	20	20	20	20	20
Total Volume (µL)	**1670**	**1684**	**1706**	**1732**	**1760**

Data acquired from calibration trials were tabulated and analyzed using Excel. Table 2 shows an example of table organization and data analysis used for each constituent of the standards.

Table 2. **Concentration of Monoolein in Standard Solutions.** The concentration of monoolein in each standard solution is given in the units of counts*seconds, defining the amount of sample detected by the GC at a given moment. The amount of sample measured and added to each standard is shown relative to the volume of the sample in the amount column. Standard deviation shows the degree of variability between measurements.

Monoolein							
Standard #	Area (counts*s) Trial 1	Area (counts*s) Trial 2	Area (counts*s) Trial 3	Amount (ng/µL)	Average	Standard Deviation	Standard Deviation Percentage
1	35483.9	33311.8	26258.5	11.98	31684.73	4823.123	0.1522
2	62247	61713	63976.7	29.94	62645.57	1183.311	0.0189
3	134843.7	122856.5	121586.3	59.88	126428.8	7315.110	0.0579
4	181798.6	167861.7	215486.6	89.82	188382.3	24485.539	0.1300
5	263101.2	331416	310134.8	119.76	301550.7	34957.023	0.1159

The values shown in Table 2 follow a general trend of increase in relation to the increase in the amount of monoolein stock added to each standard (Table 1) as expected. Calibration curves were constructed with the average of the area counts on the y-axis and the amount of stock on the x-axis of each standard. The calibration curve for monoolein is displayed in Figure 1.

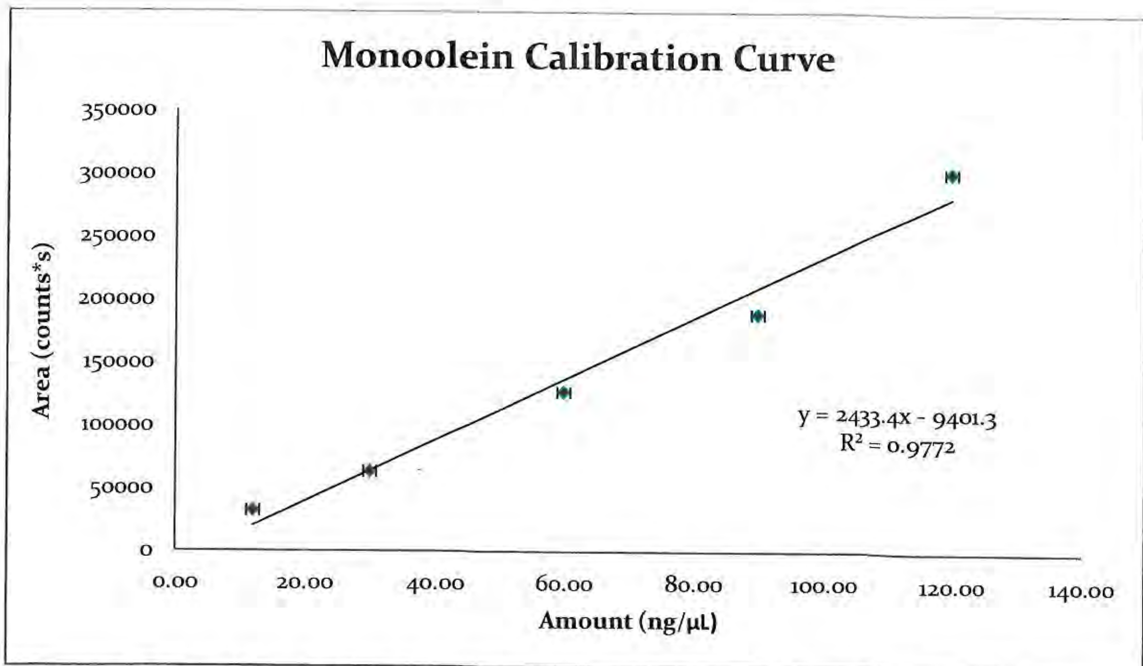

Figure 1. Calibration Curve for Monoolein. The area counts values acquired from GC analysis and shown against the respective proportion of monoolein stock solution added to each standard. Error bars express the standard deviation associated with each of the plotted values. An R-squared value of 0.98 suggests that 98% of the variation in the data can be explained by given best-fit equation.

The plotted data follows a positive linear curve defined by the best fit equation $y = 2433.4x - 9401.3$ with an R-squared value of 0.98. This value provides reason to believe that 98% of the variance in the data is described by the best-fit equation. Errors bars define the standard deviation of the data, showing a relatively tight range. Based on the results from this and the other calibration curves, it is reasonable to state that the GC to be used in sample analysis operates in a reliable manner.

Wood Chip Filtration

Experimental trials were performed for unfiltered and filtered biodiesel. In order to ensure that the samples contained a measurable amount of glycerins, a sample of crude biodiesel was mixed with a sample of B100 biodiesel. The biodiesel was poured into the filtration column without woodchips before an unfiltered sample was concocted for GC analysis. The column was then packed with wood chips and biodiesel was poured in and collected to concoct a filtered sample for GC analysis. The results from GC analysis of unfiltered and filtered samples are shown in Figures 3 and 4.

Table 3. Area Percentages of Unfiltered Biodiesel. From the GC analysis, area percentages were determined for glycerin, mono-, di-, and triglycerides along with esters. Total glycerin of the unfiltered biodiesel was found to have a mean value of 5.75% of the total volume.

Unfiltered Spiked Biodiesel Percentages					
	Area Percentage				
	Trial 1	Trial 2	Trial 3	Mean	Standard Deviation
Glycerin	0.170149536	0.204956	0.20093485	0.192014	0.019041255
Monoglyceride	1.590610081	2.140529	1.82264214	1.851261	0.276074368
Diglyceride	1.591888149	1.474729	1.2114467	1.426021	0.194841678
Triglyceride	2.217851431	2.575599	2.04814904	2.280533	0.269253674
Esters	94.4295008	94.13172	95.2324225	94.59788	0.569343891
Total Glycerin	5.570499198	6.395814	5.28317273	5.749829	0.577591417

Table 4. Area Percentages of Filtered Biodiesel. The area percentages obtained from GC analysis show the mean and standard deviation of glycerin, mono-, di-, and triglycerides in addition to esters. Total glycerin of the filtered biodiesel was found to have a mean value of 5% of the total volume.

Filtered Spiked Biodiesel Percentages					
	Area Percentage				
	Trial 1	Trial 2	Trial 3	Mean	Standard Deviation
Glycerin	0.098868789	0.081856	0.13782788	0.106184	0.028694055
Monoglyceride	1.732004863	1.017766	1.70578865	1.485187	0.40501003
Diglyceride	1.464207715	1.036804	1.51065949	1.337224	0.261205759
Triglyceride	1.629868978	2.017018	2.55508226	2.067323	0.464653498
Esters	95.07504966	95.84656	94.0906417	95.00408	0.880105659
Total Glycerin	4.924950344	4.153444	5.90935828	4.995918	0.880105659

Tables 3 and 4 display data collected from performing three trials of GC Analysis to acquire a mean value of the trials. Table 3 shows the mean values of glyceride concentrations for the unfiltered biodiesel sample, found to be 0.192, 1.851, 1.426, 2.280, and 5.749 for glycerin, monoglycerides, diglycerides, triglycerides, and total glycerin, respectively. Filtered biodiesel mean glyceride concentration values were found to be 0.106, 1.485, 1.337, 2.067, and 4.996 for glycerin, monoglycerides, diglycerides, triglycerides, and total glycerin, respectively. These values correspond to the percent of the total sample represented by each constituent. Overall, the mean values show a decrease from the unfiltered biodiesel sample to the filtered biodiesel sample, indicated that the wood chips may have had some effect in the removal of free glycerin, and subsequently, total glycerin.

The data from Tables 3 and 4 was then compiled into a graph, shown in Figure 2.

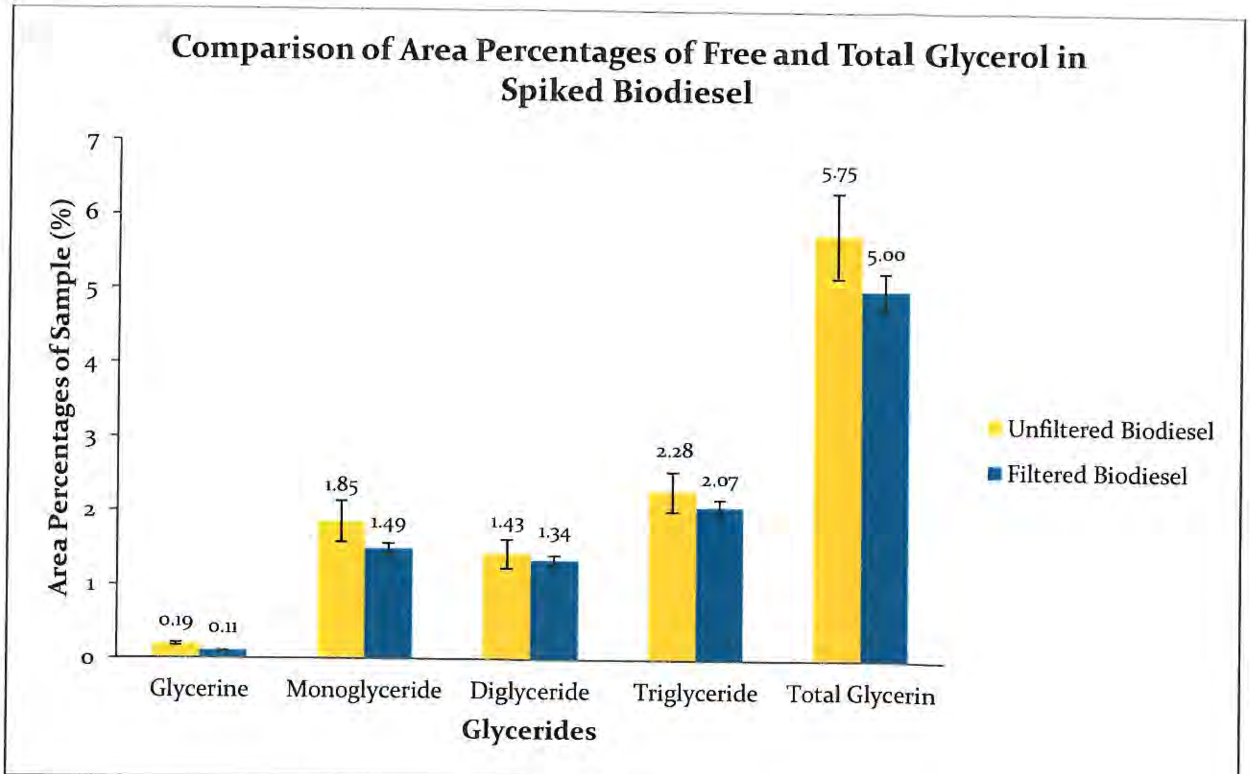

Figure 2. Area Percentage Comparison between Free and Total Glycerin of Unfiltered and Filtered Biodiesel. The values shown in Tables 3 and 4 are shown. The left column of the two-column sets represents the unfiltered biodiesel, while the right column indicates the filtered biodiesel. Standard deviation for each constituent is shown as an error bar at the top of each column. Data values for esters were not included as they would dramatically impact the scale of the y-axis.

Figure 2 provides a visual rendering of the data presented in Tables 3 and 4. In the two-column sets, the left column represents the unfiltered biodiesel and the right column represents the filtered biodiesel. The values above each column indicate the column's value and standard deviation is depicted with vertical error bars. Decreases of 45%, 20%, 7%, and 10% were observed for free glycerine, monoglycerides, diglycerides, and triglycerides, respectfully.

Discussion

The calibration curves generated from GC analysis of the five standard solutions yielded best-fit equations with R-squared values of 0.98, 0.98, 0.93, and 0.95 for glycerol, monoolein, diolein, and trioolein, respectively. These values indicate that the GC used in analysis, provides reliable detection and measurement of samples. The variability of data from trial to trial results from the nature of uncertainty in measurement of small sample volumes. Following the conclusion of the filtration trials, the injection column was removed and examined during a routine septa replacement and was found to be cracked. Although the GC still produced results, the precision of the results was compromised to a certain degree. In response to this discovery, the injection column was replaced along with the septa, ferrule, and ferrule bolt. These replacements are expected to improve instrument precision.

Figure 2 verifies the overall decrease in free and total glycerin, however, in some sets, the error bars overlap. This indicates that although a difference in the free and total glycerin of the unfiltered and filtered biodiesel was observed, the same result may not necessarily hold true if the experiment is conducted again. In order guarantee that the mean values of glycerin, monglycerides, diglycerides, and triglycerides are accurate with respect to the true mean value, the number of trials performed must be increased. A larger trial size reduces the impact any outliers that could act as leverage points, potentially skewing the data from the true mean value and subsequently, shrinking the standard deviation error bars.

Conclusion

Preliminary data suggests that using wood chips as a filter for crude biodiesel shows promise in production applications. In order to verify these results, the number of trials performed should be increased and statistical analysis applied. Improvements to the column design may result in enhanced filtration results. Repairs made to the GC are anticipated to result in more precise measurement in future sample analysis. A cost analysis will be done to show the effect of the wood chips on the overall filtration process and its improvements on the life cycle of the ion exchange resin.

Valley 25x'25/JMU IEER

Renewable Electric Conversion and Demonstration Project – Final Report

October 1, 2012

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Renewable Electric Conversion and Demonstration Project

Executive Summary

The Valley 25x25 funded project, Renewable Electric Conversion and Demonstration Project developed a renewable fuel transportation demonstration. Through a conversion, a vehicle was able to more than double traveling mileage and reach 113 miles per gallon at the peak of the test, demonstrating an immediate use and several benefits for local solar power. The project showed a repeatable 28% efficiency improvement or greater using available solar.

Transportation represents a significant energy usage sector in the Commonwealth, generally moving people and goods with the combustion of non-renewable, and often non-domestic sources. 25% of our state energy use is in the transportation sector, and nearly all of that energy now comes from fossil petroleum. Without statistically significant in-state production of oil or gasoline, and only a few million gallons of renewable biofuels such as ethanol and biodiesel, Virginia is a major importer and consumer of an unsustainable fuel. As we produce and can produce other energies, and have renewable resources, transportation alternatives represent a key method to reach the Valley's 25x'25 goals.

For this project the project team set out to transition a full sized passenger hybrid electric vehicle from imported fossil petroleum fuel source to a cleaner renewable electric fuel resource. This shows reduction of fossil energy consumption in the transportation sector through a demonstration of electrifying and increasing fuel efficiency with a common model Toyota Prius. This plug-in hybrid vehicle is well named to represent the beginning of the transition from petroleum fuel to energy supported by locally generated solar or wind systems. For the project, first a plug in conversion technology was applied to the vehicle to enhance mileage (First of a kind in the Valley), and then grid and renewable fuel systems were tested to illustrate renewable refueling.

This effort represents a transportation and alternative fuel vehicle project, as well as supporting partnerships with local industry and outreach with the local and regional community. Before and after tracking data was collected and incorporated into a case study, and the vehicle demonstrations were provided to the community.

Partners for this project included SUNRNR which provided the demonstration charger, Hymotion, which was engaged for the vehicle conversion, Virginia Clean Cities who provided technical assistance, and Pyxidus LLC, which provided the networked analysis equipment.

SUNRNR equipment was built at NeuroRestorative Virginia, a facility that provides supportive employment to individuals suffering from neurological disabilities and traumas. The conversion

was done at the JMU Alternate Fuel Vehicle Laboratory, a premier conversion and analysis facility within the Commonwealth.

The four program tasks were to:

1 – Vehicle retrofit. This involved installation of a extended plug-in battery pack in the vehicle

2 – Solar setup involving positioning the solar battery

3 – Vehicle charging and testing

4 – Leverage and outreach

Vehicle Retrofit and Conversion

An aftermarket Prius Hymotion kit was used to add an additional 5kw battery to a stock 2006 Toyota Prius. This conversion kit was a standard plug-in conversion for hybrids up until Toyota and other manufacturers introduced direct-from-manufacturer plug-in vehicles. Hundreds of Plug-in hybrid conversions were done to fleet and individual vehicles, advanced lithium ion batteries from A123. The Hymotion L5 Plug-in Conversion Module for the Toyota Prius is now discontinued and the company is focused on direct partnerships with global auto-makers. Prior to being discontinued, the hymotion battery kit cost around $10,000 for purchase and installation.

Image Courtesy of Hymotion – www.hymotion.com

The equipment was installed at JMU's Alternate Fuel Vehicle Lab by staff form the Advanced Vehicle Research Center in Danville Virginia. Installation of the additional 5kw battery was a simple process, taking two technicians one day to install battery equipment. The modification added the battery pack and reprogramed aspects of the vehicle drive cycle to engage all electric rive. This equipment was funded by individual faculty at James Madison University as leverage for this 25x/25 project.

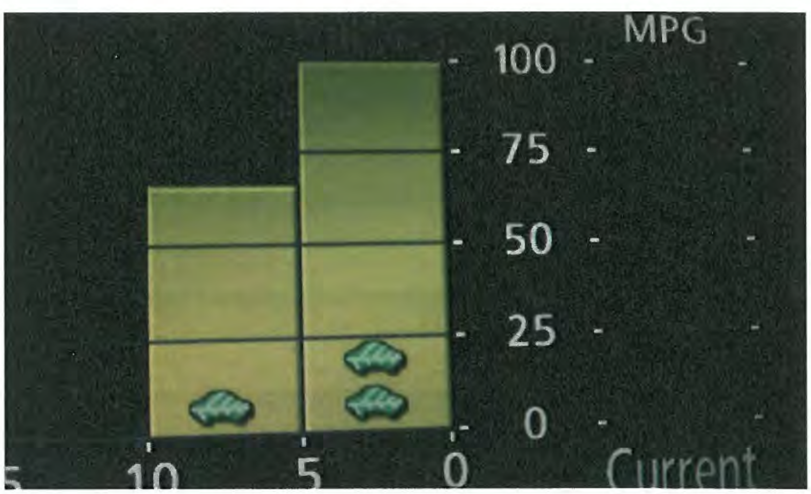
Photograph of battery installation

Here the 5kw lithium battery is installed by technicians in the rear of the Prius. Installation was done at the JMU Alt Fuel Vehicle Lab located on Main Street in Harrisonburg, Virginia.

The battery added 12 miles of all electric range, or 30 miles of hybrid electric range. It also added an additional 200 pounds to the vehicle weight, and took up space used in the trunk for storage of the spare tire and accessory cables. After the conversion, we chose to leave the spare tire in the trunk space and to tie it down using Toyota OEM tie downs.

After conversion, a brief in-town test was done to confirm vehicle operation and achieve electric operation. The system operated smoothly and enhanced electric drive was achieved.

Image of Fuel Efficiency in Early Commutes to and from JMU



The Prius has a built in graphic display of fuel efficiency. In the photo above, the display indicates the last ten minutes of a commute from JMU. This indicator shows that the early part of the journey averaged under 70mpg for the first five minutes, but reached 100mpg for the final 5 minutes. A similar cold start commute often would show 25mpg and 35mpg for a ten minute commute – this was shown in data analysis.

The charger on this vehicle takes about a kilowatt of power each hour using a standard 120 volt household outlet, filling the vehicle within four hours. Charging was done using contractor grade extension cabling and at dedicated circuits wit a Ground Fault Interruption circuit breaker.

Power Reading for Charging Unit Showing 122.7 volts.

Solar Setup:

Solar setup was a challenge, but eventually resulted in a successful demonstration of full battery recharging. Campus positioning of the solar panels was seen as a challenge and an alternate method was pursued that would enable solar charging from a canopy at a downtown gas station under construction. Regretfully, access to that facility was also a challenge. Access to on-campus wind or other renewable energy was also limited. In the end, solar charging was done through demonstration events on site at the SUNRNR manufacturing facility at NeuroRestorative Virginia.

In the photograph above, the demonstration Prius charges off of a pair of SUNRNR solar electric generator systems and two solar panels at NeuroRestorative Virginia.

Each SUNRNR represents 2,000 Watts of stored electricity – with a 3,500 peak-power surge inverter that allows clean 110/120 electricity output. The unit is available for a suggested retail price under $4,000 including a 135 Watt solar panel. To fill the battery, two SUNRNR units were used. As of 2012, the configuration of a SUNRNR enables up to three SUNRNR units to be easily used together. An additional SUNRNR would cost less than $3000 allowing full recharging for an electric vehicle to cost less than $7,000.

Two SUNRNR Units Connected

Sunrnr sells additional solar panels for just over $500.

While solar power was demonstrated in this effort, these units are compatible with any electrical source, including grid power, wind power, kinetic (bicycle), and microhydro water turbines.

SUNRNR Solar Charging Images

SUNRNR Showing 16.2 Amp Draw of Solar Charge

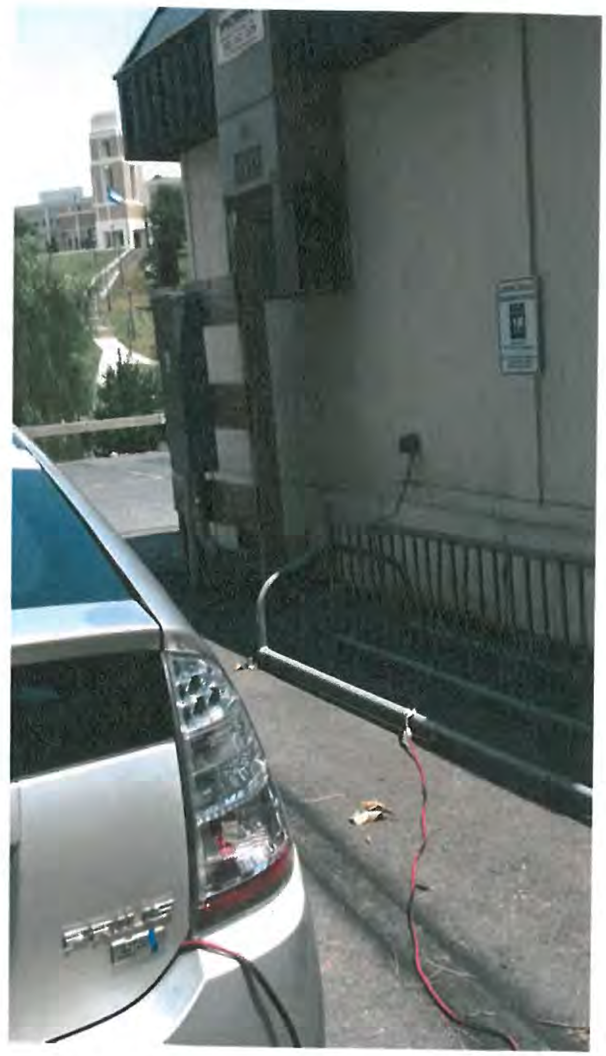
SUNRNR Showing Electrical Outlets

Solar Charging while visiting the NeuroRestorative Virginia facility was able to adequately refill the vehicle's Hymotion battery. Once solar charging for full vehicle refill was observed, standard refueling on grid electricity was done at the Urban Exchange apartment complex in downtown Harrisonburg through electric vehicle charging that is offered for free to residents of that facility.

Battery Indicator on Prius Display – Showing Full after a Solar Charge

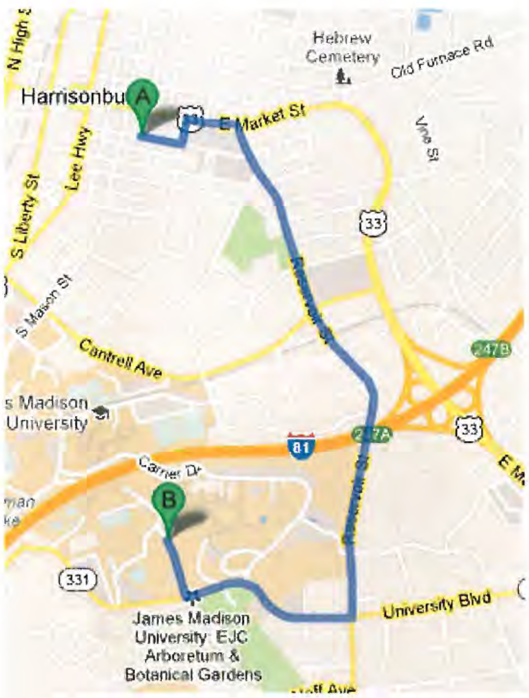
One major note of challenge was the location of charging facilities at the Urban Exchange. Two chargers at each level of the parking deck were located immediately adjacent to the elevators. Due to the proximity to the conveyance convenience, these charger parking spots were often filled with vehicles and inaccessible.

Alternative refueling spots were identified and also tested on JMU campus. In the photo below and to the right, the demo vehicle illustrates a safe top off charge at one of the available electric bicycle charging locations on East Campus at JMU. A regular household outlet provides enough power for the vehicle within four hours.



While standard outlets are frequent, the 120 volt charger on this demonstration vehicle is unfortunately incompatible with modern higher capacity and faster electric vehicle chargers available elsewhere in the Commonwealth.

Vehicle testing



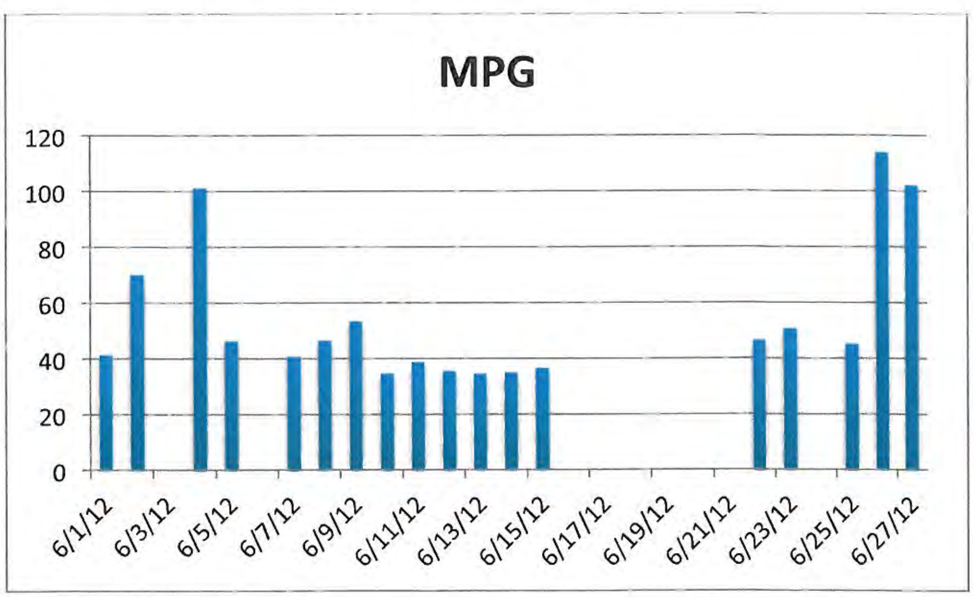
Standard Demonstration Route June 2012

Once charged, we drove the vehicle on a series of similar work commutes from downtown Harrisonburg to James Madison University (MAP). For the period of this test, highways were avoided and no air conditioning was engaged. These commutes were around two miles each way, or 4 miles a day, and a charge could cover about three days to a week of travel in the month. Other small trips were also done in this period. The data was collected using a cellular data and GPS enabled connection directly to the vehicle's ODB port. This device captured much trip data and was calibrated by the partner to set for the Prius.

Using internet enabled direct data collection we captured vehicle trip, fuel consumption, and location information for the month of June 2012.

Results

The results for the Plug-in vehicle efficiency are impressive. Data shows three days over 100 mpg while days in pure hybrid modes reached as low as 34 MPG on the hills of Harrisonburg. Combined, the trips represent an average for the month of 51 mpg.



engaging, but individuals are much more interested in available technology such as Plug-in Prius vehicles directly from the manufacturer.

Conclusions

This demonstration project showed the success of local businesses providing solar power for a significant vehicle efficiency improvement. At a conservative 28% improvement over the long term in a vehicle tank, plug-in vehicles represent one way to reach the 25% energy savings goals by 2025.

Individual can purchase Chevrolet Volts or plug in hybrids like the Toyota Prius. While this project was run on a modified hybrid vehicle, the gasoline engine almost always turned on for power assistance, as the small electric motor was not intended to provide power for hill climbing. Only once in the test did we successfully make the full trip from downtown Harrisonburg to JMU.

Full Battery at 4.33 KWh

The vehicle battery pack is 5kw, often charging only 4kw. This volume of electricity is ideal for small solar, but does not immediately replace the full gasoline vehicle.

Individuals seeking their own vehicle data can use Bluetooth ODB devices, such as the many inexpensive versions available from internet retailers. Individuals can also use dedicated computers like the Scangauge II to connect and interpret vehicle data. Both types of equipment were used in this analysis, but none provided as much detail and consistency as the GPS and Cellular data enabled technology used.

Battery conversion system is expensive at $10,000, but plug in and electric vehicles are available as a consumer option and accessible with a current tax credit. Solar charging with two SUNRNR units would only run around $7,000, though an additional solar tax credit of 30% could bring costs down to $4900. This seems expensive, but is around the average that a household budgets for a single year of gasoline. This small amount of electricity is demonstrably enough for many daily commutes in Harrisonburg and can significantly decrease fossil fuel oil use. The trips in this effort only needed 1/3rd of that electricity – allowing for vehicle to be used for three days without a recharge. For a consistent charge for full commuting for this example, One SUNRNR extracting 1kw of power daily would suffice.

This demonstration is directly analogous to retail vehicles like the 2012 Toyota Plug-in Prius. Three SUNRNRS could consistently likely provide a full battery and take that vehicle entirely off of fossil fuel for individuals with a 12-mile commute or less. For a larger vehicle, different battery packs would require additional power. For example, the Chevrolet Volt provides 40

Vehicle Usage Data June 2012

Date	Mileage	Fuel	MPG	
6/1/12	1.99	0.0484273	41.19305604	
6/2/12	3.57	0.051045309	69.98393959	Charge Event
6/4/12	10.10	0.099915641	101.0790902	Full battery
6/5/12	3.39	0.073457502	46.15027782	Depleting battery
6/7/12	4.79	0.117756739	40.70248811	
6/8/12	2.30	0.049628604	46.43812572	
6/9/12	12.21	0.228692777	53.37740876	
6/10/12	4.95	0.142832867	34.62758459	
6/11/12	16.23	0.419865585	38.65668705	
6/12/12	8.39	0.236180897	35.52949482	
6/13/12	9.17	0.266376231	34.42362731	
6/14/12	11.06	0.316644299	34.92578245	
6/15/12	2.40	0.065795165	36.48745261	
6/22/12	6.86	0.14784	46.383802	Charge Event
6/23/12	5.34	0.1056	50.57394513	Full battery
6/25/12	4.52	0.10032	45.04047976	Depleting
6/26/12	28.55	0.2508	113.8441269	Charge Event
6/27/12	6.74	0.066	102.110159	Depleting battery
Totals	142.57	2.787178913	51.15083755	

On days with plug-in kit used, there was great mileage savings On other days, the vehicle performed with comparatively less efficiency. Vehicle preformed significantly worse than flatland expectations due to the fact that Harrisonburg has a lot of hills. The fuel use data is reinforced with decreased fueling even at highway and greater speeds – now the Plug-In demonstration Prius can achieve 450 miles to a tank of unleaded gasoline compared with a 350 maximum previously. Comparing long term data (tank) with spot data (133 mpg over 28 miles) This demonstration shows 28% to 300% improvement in efficiency and decrease in unsustainable fossil fuel use.

Demonstration

This vehicle was demonstrated at electric vehicle meet-up events in Richmond Virginia, as well as shared with on campus Alt Fuel Vehicle Lab staff. The vehicle was on site when Harrisonburg Virginia commissioned their first electric vehicle charger. Demonstrations were generally miles of electric only driving for it's 16kw battery pack- this vehicle may need 8 SUNRNRS for a daily charge. With three SUNRNRS combined, A Chevy Volt would only be granted 1/3rd of a charge, or 12 miles, daily.

Electric bikes often require less than a single kilowatt of charge and provide many miles of emission free travel. A single SUNRNR would easily and consistently refuel even a small fleet of electric bikes.

There are significant benefits to the local community in adoption of techniques used in this demonstration. The community loses harmful emissions, but potentially keeps transportation dollars.

Each SUNRNR is manufactured locally to the Shenandoah Valley through a partnership with NeuroRestorative Virginia. Participants have at NeuroRestorative have worked with SUNRNR each week, assembling parts and equipment for each generator. Currently SUNRNRS are all produced in the Valley.

The Project did a site visit to review the great work done at SUNRNR assembling components. It was rewarding to see community engagement in manufacturing and distribution of clean energy equipment.

Dissassembled SUNRNR at the NeuroRestorative Virginia Facility

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The project team was grateful for the chance to advance this effort. This project illustrated the conversion and fueling of a traditional vehicle with a modern clean zero emissions fuel. By transitioning from unsustainable gasoline to cleaner renewable sources of energy we can advance numerous federal, state, and local goals.

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saved as Hartshorn_Geothermal_Final_Report_110930.pdf

Valley Geothermal Project

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On 14 March 2011, Tony Hartshorn of the Department of Geology & Environmental Science at James Madison University (JMU) submitted a proposal to JMU's *Institute for Energy and Environmental Research* for 25x'25 Seed Research funding of a research program titled "Mapping geothermal potential across the Shenandoah Valley," henceforth the "Valley Geothermal Project" (VGP). An award letter was received on 8 April 2011.

That proposal stated funds (~$9K) would be used to fuse soil temperature data with energy usage statistics compiled (voluntarily) and analyzed to assess the return on investment associated with geothermal heat pump (GHP) systems. Funds were also to be used to develop a "clearinghouse of 'geothermal success stories' (a dynamic map with links to video interviews)" that, in turn, might "catalyze the Valley's 25x'25 efforts."

This report summarizes progress to date. It has 8 sections, with #3-6 representing deliverables.

1. Executive summary
2. Timeline
3. Web-accessible soil temperature data
4. Electrical usage data: what happens to your bill after you install a GHP?
5. Educational resources
6. Clearinghouse/wiki of GHP systems (and future work recommendations)
7. Future funding sources
8. Conclusions

1. Executive summary

In Spring 2011, Tony Hartshorn, an Assistant Professor with the Department of Geology & Environmental Science at JMU, received ~$9,000 as Seed Research Funding from Valley 25x'25 to promote the use of geothermal heat pumps (GHP).

GHP is an energy efficiency approach that can dramatically reduce energy consumption associated with heating and cooling buildings, from residential to commercial applications. They should not be confused with geothermal sources of electricity, which are industrial-scale operations that tap the heat of the Earth to generate steam, which is used, in turn, to produce electricity.

As part of this project, the VGP team (Hartshorn and three research assistants: Jeremiah Vallotton, Fernando Perez, and Liz Weisbrot) decided to distinguish between these two geothermal facets of our lives by using a lowercase "**g**eothermal" for the energy-efficient heat pump and uppercase "**G**eothermal" for the electrical generation complexes. This project focused exclusively on the former.

There were three deliverables from the VGP.

1. We generated a web-accessible soil temperature dataset with standalone dataloggers. Users can compare soil temperatures across 5 campuses (from south to north): Roanoke College, Washington & Lee University, Virginia Tech.'s McCormick Farm (Raphine, VA), JMU, and Shenandoah University.

Our results suggest that JMU has the warmest summer soil temperatures of all five locations, an unexpected result given its relatively high elevation (~1300 feet): air temperatures, and by extension soil temperatures, are generally cooler with increasing elevation. One factor that may confound comparisons between campuses, and helps explain JMU's relatively warm soils, is that the installation site for JMU needed to be adjacent to a paved surface, and the 25-foot-wide service road next to the soil temperature probes most likely creates an artefactually warmer set of conditions during the summer months.

2. The VGP team also assembled energy usage statistics on a voluntary basis from 25 Valley residents. These houses represented a spectrum from multi-resident apartments to single person homes, with square footage ranging from 675 to 5000 ft^2, and with a variety of energy systems (including GHP, HVAC, space heating, fossil-fuel based heater, and others). These data were collected with the intention of examining how electrical usage changed following installation of a GHP, as this would provide a real-world example of energy savings specific to a Shenandoah Valley installation.

Unfortunately, several individuals with access to GHP clients (who might have been willing to share their electrical usage) were extremely difficult to track down. Nevertheless, we obtained electricity data from two individuals who had monitored electrical consumption before and after their installation of a GHP. In aggregate, these data showed that there is a small decrease in total kilowatt-hours used after the GHP is installed, and then only in the more extreme months in the summer and winter. This suggests that GHP may not be quite as cost-effective as advertisements may claim, although there are still savings, however small, that will continue to accrue for however long utilities are used. As one counterpoint, however, we did meet and interview a JMU staffer who installed his own GHP in his Bridgewater backyard for a total out-of-pocket cost of ~\$3000, and with a payback period of <2 years.

3. Finally, the VGP assembled an educational 6-minute available via YouTube.

2. Timeline

The intended start date of 1 April was not possible due to some complications. Hartshorn received an award letter on Friday, 8 April, requesting coordination with IEER staff 'to finalize the budget' and noting that budget 'activity will not begin until an acceptable statement of work is negotiated and deliverables are finalized.'

These negotiations were resolved the following week, and on 12 April, R. Phillips of Geology & Env. Science was able to add the org code 529320 to his SPCC, with all paperwork for purchases to be run through B. Rohlf, including a PO for the proposed four Onset Computer Corporation H21 dataloggers, each with three soil temperature probes (~\$2K).

On 14 April, the datalogger PO was approved by B. Rohlf, and these dataloggers and probes arrived several days later. On 19 April, I received notification that one of the project staffers (J. Vallotton) could begin work. I would later hire one other employee, L. Weisbrot. Due to a miscommunication on the part of Hartshorn, funds paid to Hartshorn were indirectly used to support a third employee F. Perez.

On 3 May, J. Vallotton and Hartshorn attended the Geothermal Energy Technology and International

Development Forum (www.geo-energy.org) in Washington DC. This proved a quite serendipitous event, as we made numerous valuable contacts.

In May, the VGP team obtained permission from collaborators at four Valley educational institutions (Roanoke College, Washington & Lee University, Virginia Tech's Agricultural Experiment Station (McCormick Farm) near Raphine, and Shenandoah University) to install dataloggers and soil temperature probes. These dataloggers recorded soil temperatures at 3 depths for a period of approximately one month (details in Section 3).

On 26 May, Hartshorn requested that B. Rohlf (IEER) submit a work order to Facilities Management for the installation of soil temperature probes at 3 depths in the smallest hole possible near the southernmost corner of the solar panel array that lies southwest of the main entrance to the ISAT complex. On 1 June, Hartshorn learned that this work order could not be processed through IEER, so R. Phillips submitted the work order on behalf of Hartshorn's department that same day.

This soil pit was eventually (and happily) discovered by Hartshorn to have been dug on 27 June; soil temperatures were monitored beginning 5 July and are still being monitored to this day. It is expected that at least 2 years of monitoring data will be captured with this equipment in its present location.

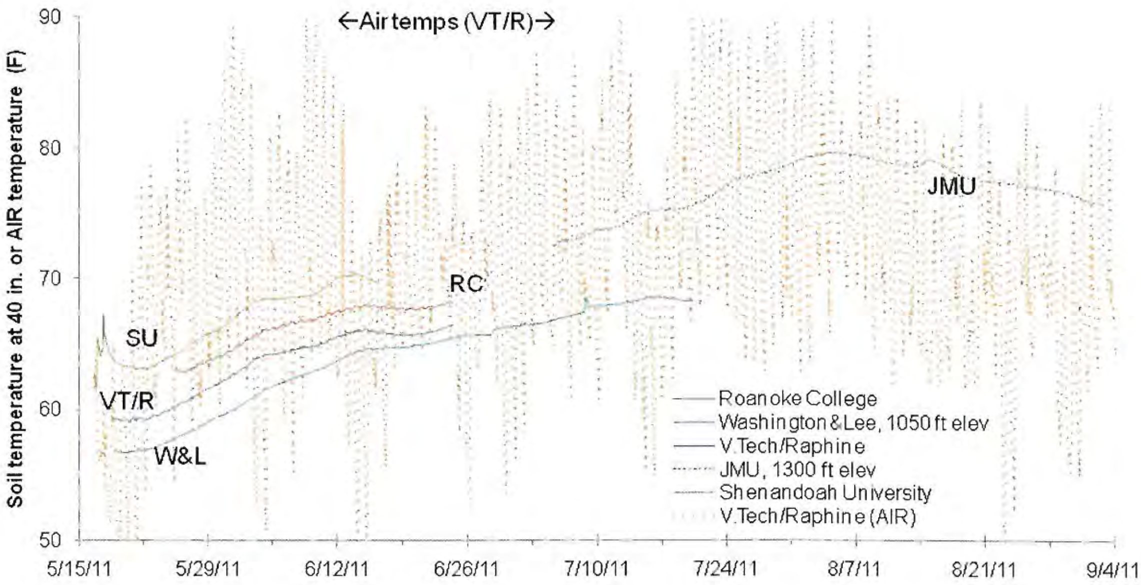
A photo album of most of these sites was created. Pictures were not available from Roanoke College.

Overall, this was a very successful project, particularly considering the compressed timeline (<4 months).

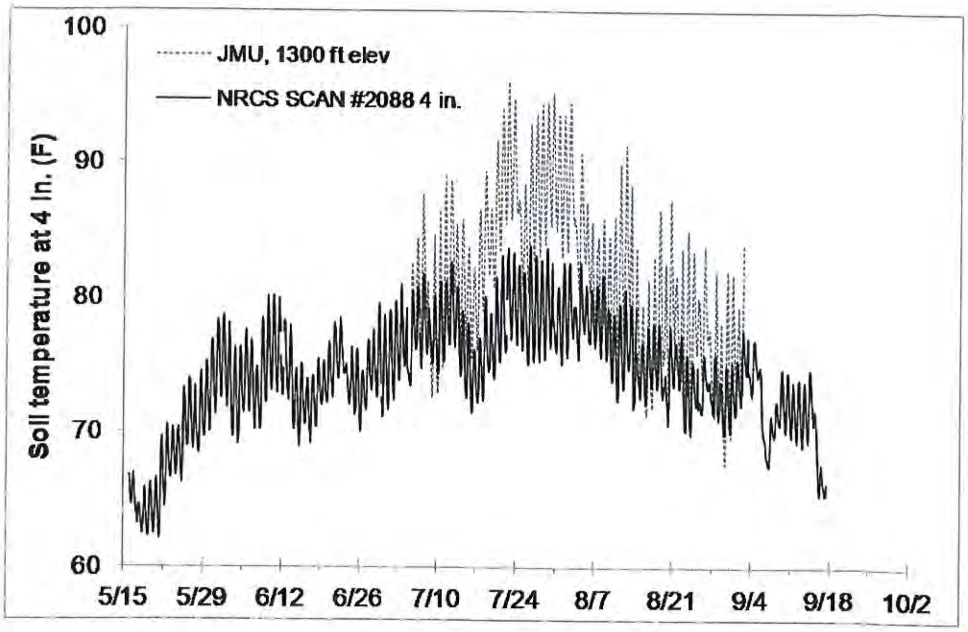
3. **Web-accessible soil temperature data**

We were interested in recording soil temperatures to learn which of the five participating institutions had the warmest soils and which the coldest soils during the Summer 2011 project period of performance (before 31 July 2011).

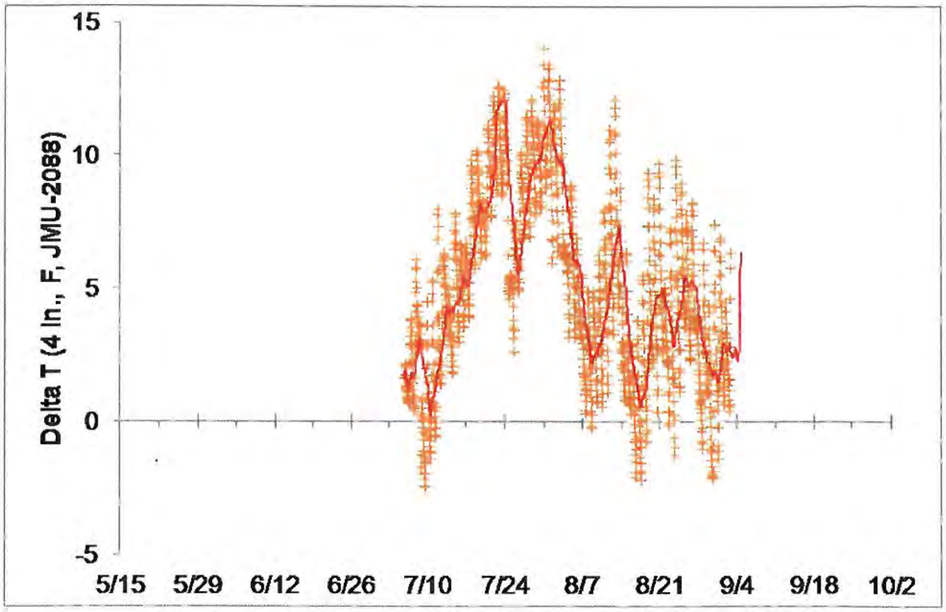
In all, we calculated ~5400 average hourly temperatures from each of 3 depths: 10 cm (4 inches), 50 cm (20 inches), and 100 cm (40 inches). Each of these averages was derived from 30 readings, acquired at 2-minute intervals. We used Excel's Pivot Table tool to extract averages, and then graphed these data.



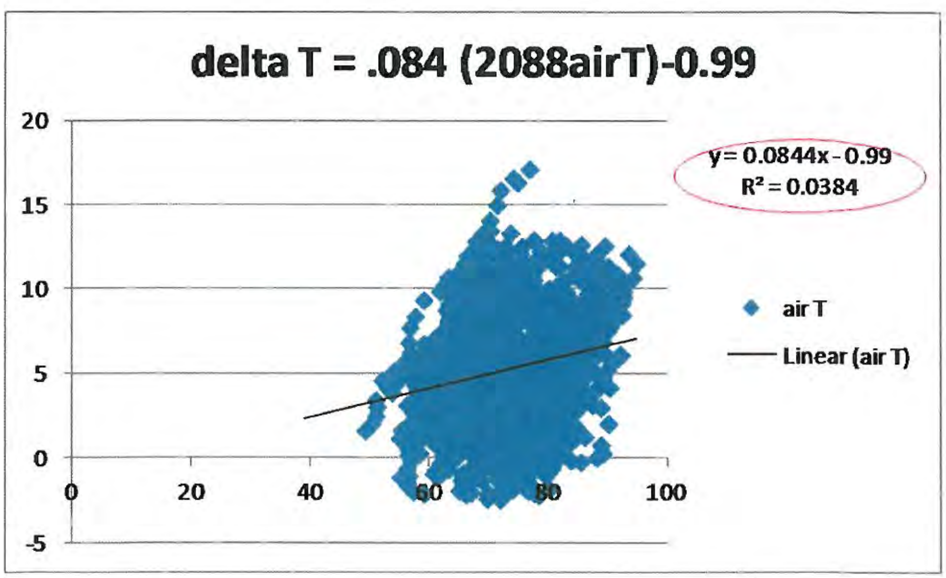
This graph shows air temperatures with brown, dotted lines. These are quite variable over the monitoring period (mid-May to early September 2011). By contrast, hourly soil temperatures at 40 inches are much smoother. An inspection of soil temperatures at 40 inches across the 5 campuses would suggest that JMU's soils are much warmer than the other campuses. This is clearly evident from a comparison of Washington & Lee's deep soil temperatures and JMU's deep soil temperatures over the same interval.



This graph shows the much greater variability at a depth of only 10 cm, or 4 inches. This graph contrasts hourly data from the JMU site (at base of eastern 4x4 post holding up the educational sign promoting the HIllside Naturalization Project, south of the ISAT building) with that from the Virginia Tech. McCormick Farm site, which reports (in real-time via the Internet: http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=2088&state=va) hourly soil temperature data, among other variables. JMU's soil temperatures are clearly warmer than comparable depths at McCormick Farm.



This graph plots those differences, on an hourly basis, as a "delta," or difference, calculated as JMU soil temperature - McCormick Farm soil temperature. Positive values indicate warmer temperatures at JMU. A 10-day running average (in red) shows that this difference can occasionally reach 10 degrees F.



This graph represents our efforts to explore factors that might possibly predict the magnitude of the warming evident between JMU's and McCormick Farm's soils. Air temperature does *not* predict the magnitude of the deltaT, with less than 5% of the variance explained.

In short, our data suggest that JMU and Shenandoah University (i.e. the northern Shenandoah Valley) had the warmest soils, although a direct comparison across institutions is hampered by the delays associated with the installation of monitoring equipment on JMU property. Nevertheless, the overall graphs of soil temperatures from 40 inches depth show that JMU's soil temperatures are much higher than soils at comparable depths at other institutions. Careful extrapolating of JMU's temperatures back into May would likely lead to the same conclusion.

It is worth reiterating that one variable that confounds any comparison across campuses is that we were required, in order to be compliant with the Americans with Disabilities Act, to install the JMU datalogger from a wheelchair-accessible location. Unfortunately, because the soil temperature probes are within feet of a massive 25-foot-wide concrete service road, it is quite likely that heat loading during the day, and heat unloading during the night, produces artefactually warm soils in the adjacent strip, where the datalogger is located.

The thermal inertia represented by the concrete service road likely helps explain why JMU has warmer soils than the other campuses we monitored. That said, the other northern Shenandoah Valley location (Shenandoah U.) had similarly higher soil temperatures than the more southerly locations, so the JMU temperature may also reflect this difference.

For future research, one of our VGP recommendations is to enable the additional collection of soil temperature data from places less affected by artefacts such as this service road. ISAT faculty have expressed interest in our soil temperature data for teaching and research purposes.

A summary Microsoft Excel workbook will be made available via this website: sites.jmu.edu/soildoc/research/.

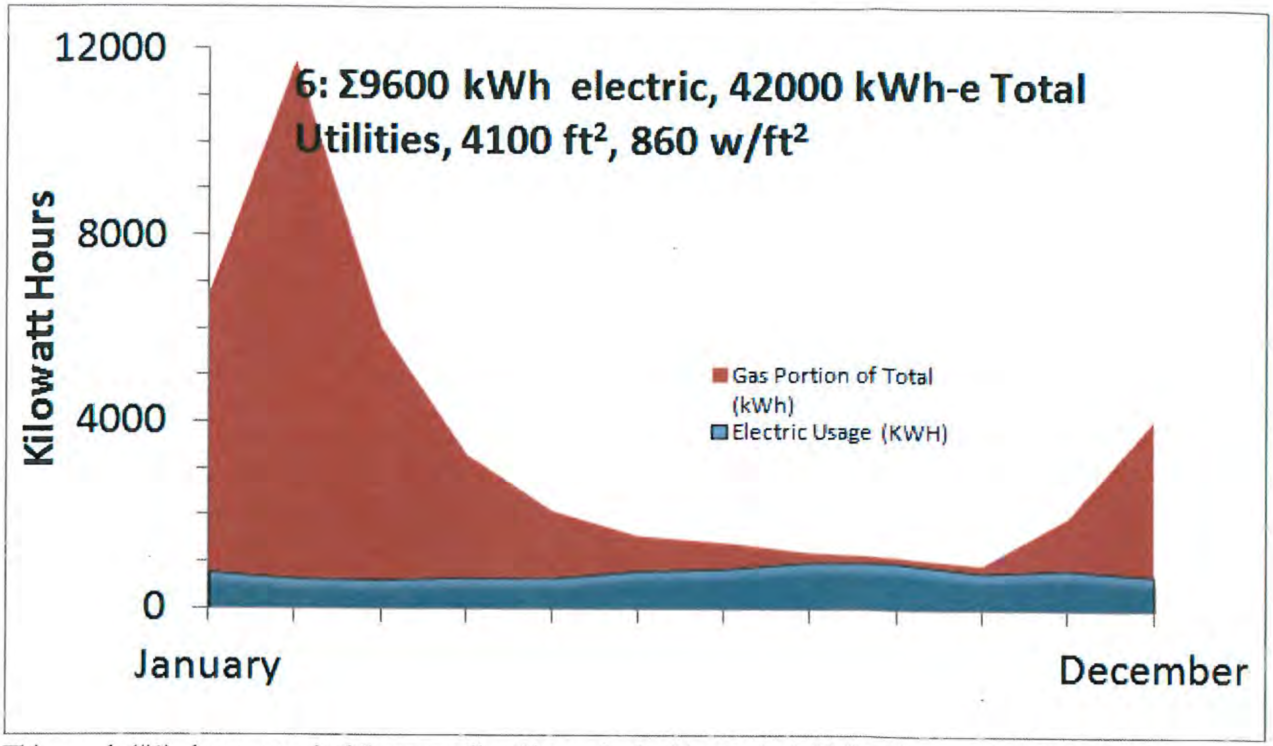
From an efficiency perspective, and as the first graph indicates, the "coolest campus," or at least the campus with the coolest summer soil temperatures, appears to be Washington & Lee, and this may reflect either the composition of the soils (the site is largely "riverjack" or large alluvial stones and boulders) or its relatively low elevation, where it can receive cold air drainage.

Clearly soil temperatures are more moderate than air temperatures, but our pilot data suggest that there might be important regional considerations for any geothermal heat pump design, especially those that plan on horizontal loop installations. We have not yet defined the optimum depth for a horizontal installation on the JMU campus, but this depth will be a balance between the added excavation costs of deeper trenching combined with the heat capacity of the soil (both for "pulling" heat in the winter and "pushing" heat in the summer) as well as the requirement that the heat exchange system lie below the "frost line."

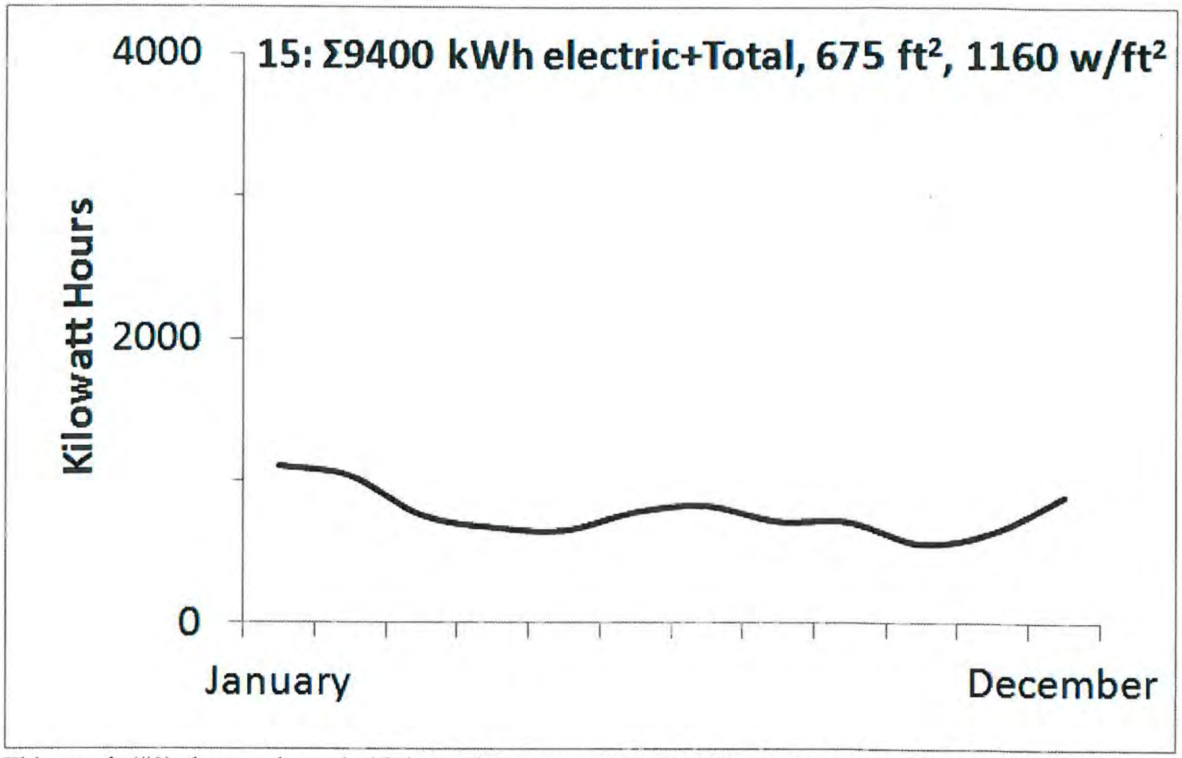
4. Electrical data survey and analysis

We managed to collect electrical consumption data from 25 individuals. We expected greater participation from both Hartshorn's department (5 of 19 households affiliated with the department provided data, including Hartshorn) and from IEER staffers, but asking individuals to share their electrical bills is a tricky business. It is worth noting that future research efforts would do well to collect data from several JMU-owned single-family homes near campus that have their own meters.

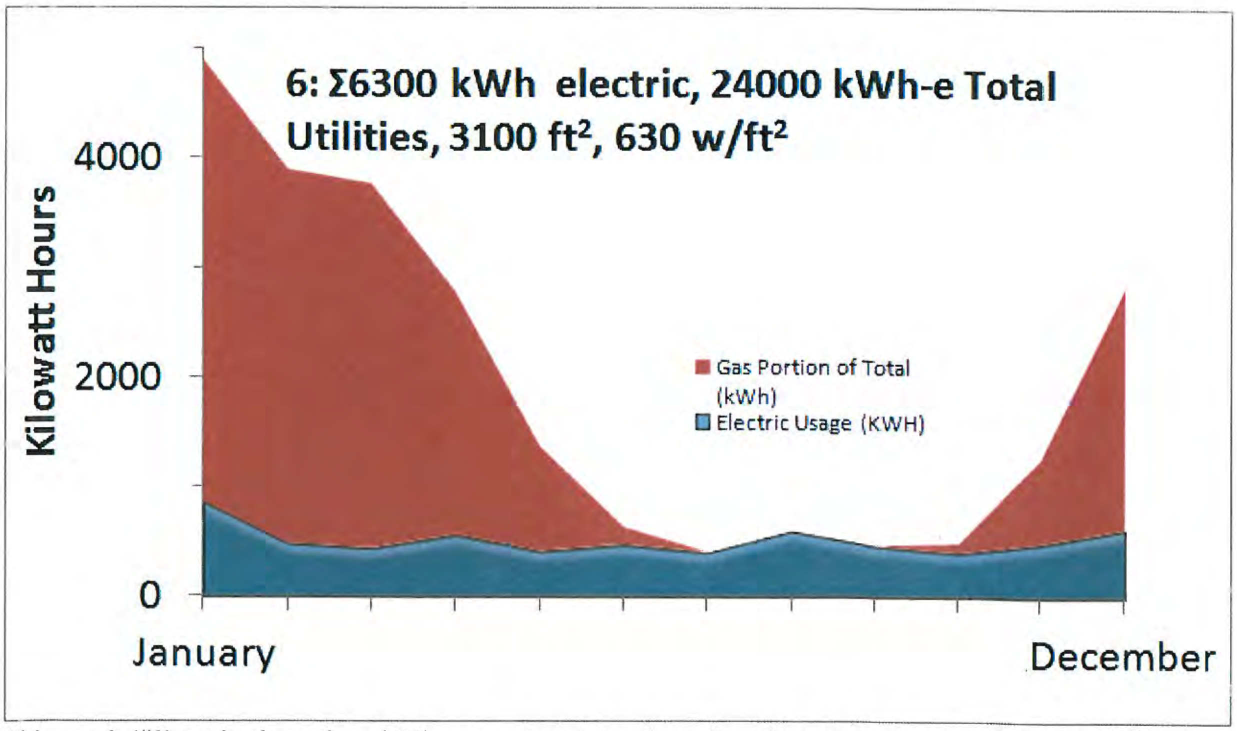
We compiled the data and examined both seasonal patterns as well as a measure of electrical consumption intensity, which we calculated as watts per square foot.



This graph (#1) shows a typical "gas guzzling" home in the Shenandoah Valley for energy. This ~4000 ft^2 home consumed about 10,000 kWh of electricity over the course of a year, but this consumption was dwarfed by natural gas consumption during the winter months, for a total of 42,000 kWh-equivalent. This graph highlights the importance, again for any future research efforts, of being able to document the energy mix consumed by utilities. We used standard conversion factors to get from CCF natural gas to kWh. This household had an energy intensity of 860 watts/ft^2.

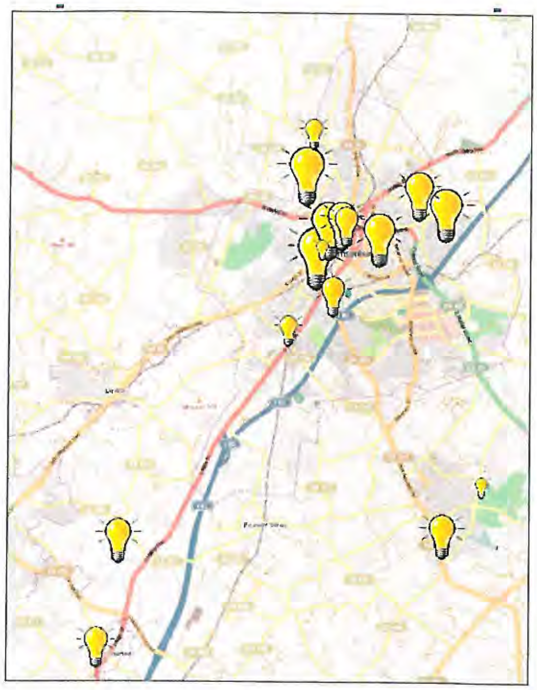


This graph (#2) shows a household that only consumed 9400 kWh. Energy intensity was 1160 w/ft².



This graph (#3) again shows how kWh may not capture a home's entire energy consumption, especially where a household uses gas or oil for heating; this number can be a disproportionately large fracion of the total energy usage.

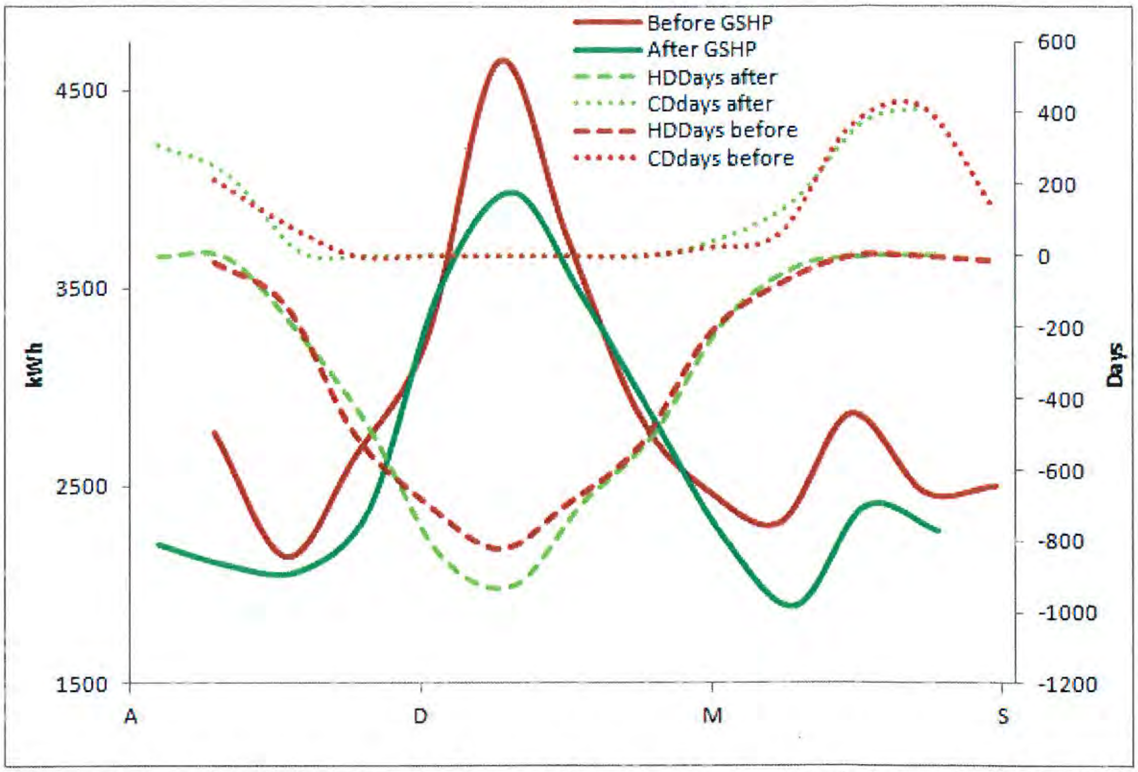
We then plotted those data in ArcGIS (screenshot below), with sizes of lightbulbs scaling with electricity intensity.



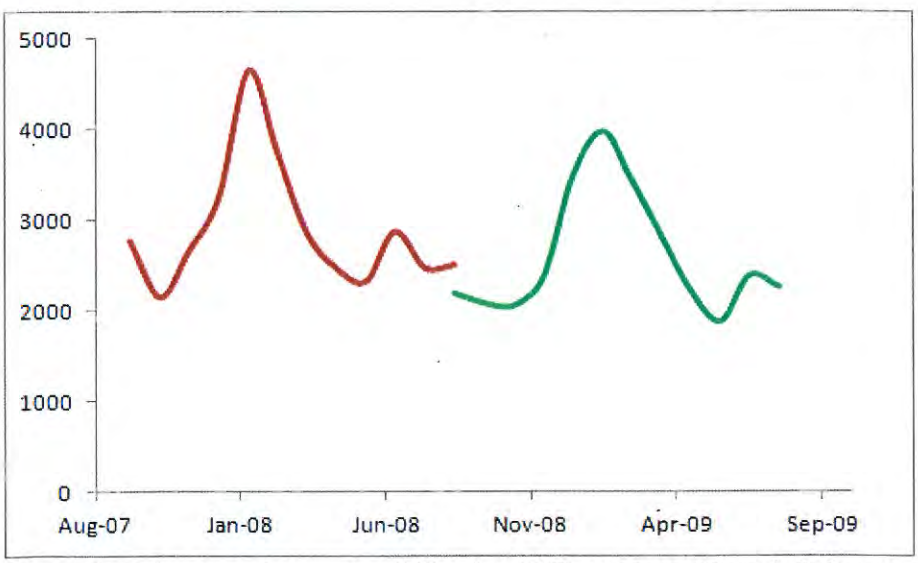
We did not have sufficient human or technical resources to generate a dynamic map of the electrical consumption data outside the ArcGIS environment.

One of the most interesting results from our survey was that we were able to compare electrical consumption before and after the installation of a GHP in 2 cases. The graphs below show the "before" and "after" trends for installed GHP systems. There is clearly a difference between them, but it is only ~275-500 kWh saved per month on average for the first household (about $50/month, or $600/year). For a system costing $20,000, this would translate to a ~34 year payback.

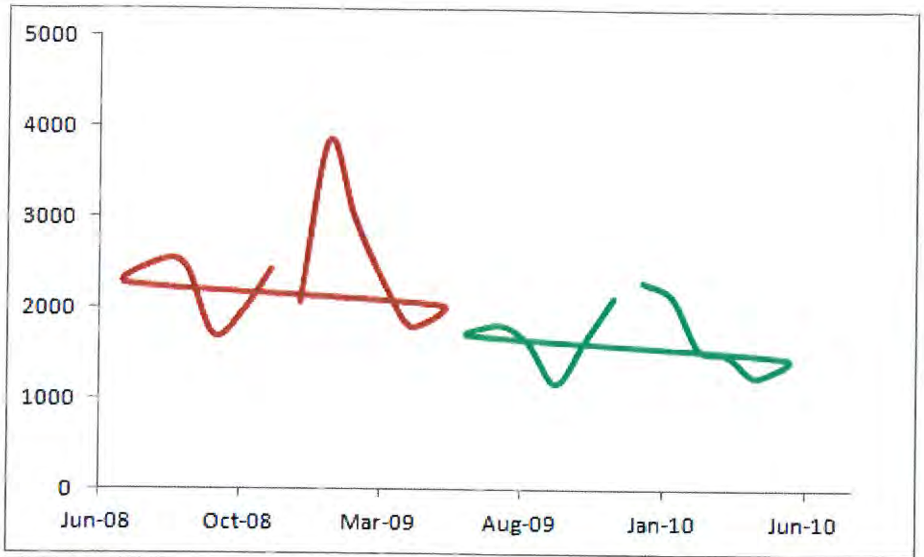
The financial savings of GHP are most evident for the hottest and coolest months, but not the milder months in Spring and Fall. When changing to a GHP system from a fossil-fuel based system, however, the savings may be drastically greater, given the amount of kWh used by fossil fuel for heating (see graphs 1 and 3). From our admittedly small sample, then, we were forced to conclude that the grandiose claims of the GHP industry of ⅓ energy savings are not necessarily true, at least for some households.

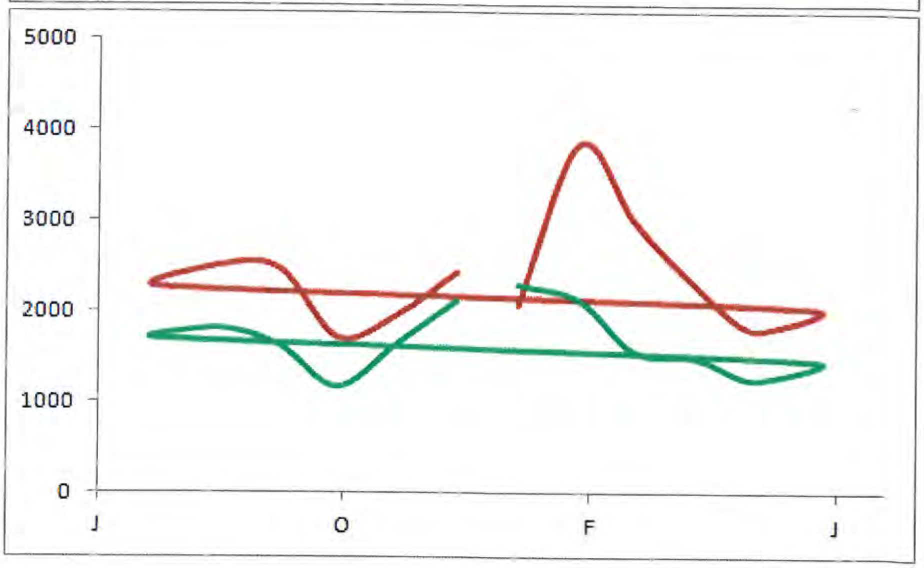


This graph shows electrical consumption by one of our survey respondents before (red solid line) and following (green solid line) GHP installation. The gap between the solid lines represents the kWh savings of the GHP system. Any comparison across time requires an additional assessment of whether the number of cooling degree days (summer; fine dotted lines) and heating degree days (winter; dashed lines) are the same. In fact, these data suggest that after the GHP was installed, cooler temperatures (lower heating degree days) prevailed, and there was still an electrical savings.



Some of our data hinted at the possibility that GHP could provide an infinite source of energy, but we hope to examine this suggestive pattern in greater detail in the future.





To obtain data, we developed a pamphlet to solicit energy consumption, and distributed this pamphlet on two weekends at the Harrisonburg Farmer's Market through partnering with Virginia Master Gardener's Association.

In addition, we also produced a large poster that was similarly presented one Saturday at the Farmer's Market to work up interest in the project, and which now resides in a prominent place for students to read in Memorial Hall.

EXAMPLE EMAIL TEXT OF SURVEYS:

Hi all,

Would you be willing to contribute *your* energy consumption patterns to our 25x'25 project, which aims to prototype a map of energy consumption patterns across the Shenandoah Valley?

Thus far we have about a dozen records, and we'd like to both broaden and densify our map.

More information on 25x'25: http://valley25x25.org/.

If so, please contact Liz Weisbrot or Jeremiah Vallotton directly (cc'd). They will then contact you and coordinate with you for transfer, be it hardcopy, snapshot of an online history, etc.

Thanks very much,
Tony

Hi all,

I hope you're all having a great summer.

I apologize for the mass email, and any duplications, but I'm wrapping up a community data-mining exercise and would appreciate it if you'd share your most recent year of electrical consumption data for our mapping project.

Attached are some of the electrical usage summaries we've collected from Harrisonburg area folks, and if you'd be willing to share

1. your address
2. whether your hot water is electric (Y/N)
3. whether you have AC (Y/N)
4. whether you have electric heat (Y/N)
5. the number of individuals in the home, including subletters
and
6. the square footage of your home

my team would like to add you to our map.

Data (or simply a 1-second screengrab of your online electric account history! for an example see attached) and answers to #1-6 should be emailed to jeremiah.vallotton@gmail.com (cc'd).

And please spread the word to anyone else who might be willing to share these numbers. We will **anonymize** the data before it is used/shared, but your address will help us map (**coarsely**) usage across town. Our hope is that this might then be useful for estimating the payback periods of different types of efficiency investments.

And I don't want to lose my bet with my lab group on how big a range in values we'll see...

This project reminds me of how, when you fly a plane, very few folks are paying exactly the same fare to get from A to B... but even fewer folks discuss it.

Thanks!
Tony

5. Educational resources

Based on some of the previously outlined work, plus the outreach efforts described in the next section, we developed a 20-minute powerpoint presentation. Additional education resources include:

a. A coloring book: http://www.igshpa.okstate.edu/pdf_files/publications/iggywb.pdf
b. Geothermal energy websites including: http://www.getgreenair.com/geothermal ; http://www.igshpa.okstate.edu/geothermal/residential.htm ; http://www.geothermalgenius.org/ ;http://www.carbondiet.ca/green-success-stories/geothermal-heating-and-cooling.html ; http://solarserdar.blogspot.com/2011/03/ccres-geothermal-energy.html ;http://sample.hendricksendesign.com/pages/3.6.html
c. International Ground Source Heat Pump Consortium (www.igshpa.okstate.edu).
d. Geo-exchange (http://www.geoexchange.org/)
e. http://www.ubeg.de/downloads/GeothermalHeatPumps.pdf

6. Clearinghouse/wiki of GHP systems

VGP outreach efforts began in earnest on 3 May when Vallotton and Hartshorn attended a conference in Washington DC. There we met a number of contacts, including the creator of the Virginia Tech. website that we referenced in our proposal, Professor Saifur Rahman. Professor Rahman is Director of the Advanced Research Institute, based in Arlington, VA (http://www.air.vt.edu). That website has recently been updated and provides very valuable--although geographically generic--educational resources related to GHP technology (http://www.geo4va.vt.edu/).

Unfortunately, we were not able to obtain graphic design or website support through IEER or Valley 25x'25. As the PI Hartshorn is inexperienced when it comes to web-based programming, a stopgap approach was taken and VGP resources are being deployed through a "child page" on Hartshorn's personal website: sites.jmu.edu/soildoc/research/geothermal/. Eventually, deliverables should be available on the valley25x25.org website (http://valley25x25.org/projects).

In terms of outreach, Hartshorn made an attempt to spark some 25x'25 synergies with an emailed invitation on 23 May to 6 other 25x'25 Seed Research grantees, but this effort ultimately fell flat. The VGP team (Hartshorn, Vallotton, and Perez) look forward to meeting some of the other grantees for the first time at the October 10, 2011 Valley 25x'25 Research Review.

Vallotton and Perez promoted the Valley Geothermal Project at the Harrisonburg Farmer's Market on July 23rd. Reaction was positive.

In addition, Hartshorn promoted the VGP at an invited talk for the Bridgewater Ruritan Club on 6 June 2011. That event led to a number of contacts with GHP that could be followed up as part of future work, including Edgar Simmons, 540.421.1756, edsimmjr@aol.com; General Buss Rachel; Terry Slabaugh, Habitat for Humanity; and Frank Will. Forrest Frazier facilitated Hartshorn's presentation at Turner-Ashby High School.

As part of our VGP, Perez orchestrated a meeting between Heidi Schweizer (http://www.wix.com/arktect/heidischweizerarchitect; Roanoke, VA), Dave and Kenlin Peters (http://www.shhomes.net; Southern Heritage Homes, Rocky Mount, VA), Jeff Tang, Vallotton, Perez, and Hartshorn on 20 September. This informal working group, tentatively called the Green(Clearing)House seeks ways of convincing municipalities, homeowners, and developers to adopt more energy-efficient approaches as part of low-income housing initiatives, as has recently been demonstrated with a 217-house development via Habitat for Humanity in Oklahoma (e.g., http://www.igshpa.okstate.edu/pdf_files/publications/ hopecrossing_cs.pdf). These efforts may work synergistically with the recently created Consortium for Intelligent Grid Research, Analysis & Education based out of Virginia Tech (http://www.cigrae.ari.vt.edu/).

After the VGP proposal was submitted, Hartshorn learned that one of the renovated dormitories on campus, Wayland Hall, had recently had its heating and cooling system retrofitted with a GHP. This vertical system consists of 40 ~600' wells. In conversations with staff at Facilities Management familiar with the project, one of the biggest surprises was that the first wells produced more than 200 gallons of water per minute, necessitating emergency measures to cope with the unexpectedly high flow rates.

Unfortunately, follow-up efforts by Hartshorn to learn more about the Wayland Hall GHP system have been unsuccessful, despite numerous productive discussions with the Office of Residence Life at JMU, the project architect (VMDO, Charlottesville, VA), and even staff from Facilities Management. It was hoped that some of what the VGP had developed as educational materials might have transference to Wayland Hall, and Hartshorn is still optimistic that JMU will soon be deploying state-of-the-art visualizations and communications materials showcasing the return on investment—at numerous levels, from economic to environmental—of this large-scale GHP.

Hartshorn did receive a very helpful white paper from contacts within Facilities Management, titled "JMU: Renovation of Wayland Hall--Sustainable design options for energy and water conservation" prepared by VMDO Architects and Lawrence Perry & Associates on 13 August 2009.

Finally, it appears that there may be some follow-on outreach potential with the Governor's School, initiated via Jeff Tang. Hartshorn is in contact with A. Staples, and will propose that students at the Massanutten Regional Governor's School (http://www.edline.net/pages/Massanutten_Regional/) install a soil temperature datalogger on that campus in order to document how much more efficient heat exchange with the soil is than with conventional systems, which exchange heat with the air.

It is our expectation (Hartshorn, Vallotton, and Perez) that the single most impactful contribution of this project will be the 6-minute video summarizing some of our VGP findings and pointing interested individuals toward additional resources. This video will be available on YouTube. Any future interviews should include Gregg Chevalier, who built and installed his own horizontal GHP in his double-lot in Bridgewater for ~$3000. Mr. Chevalier is a Supervisor of HVAC systems at JMU, and is quite knowledgeable about GHP.

7. **Future funding sources**

A quite useful newsletter that includes future funding sources can be obtained by contacting leslie@geo-energy.org. Weekly newsletters with this type of content (copied below) can be obtained on a free subscription basis (http://www.geo-energy.org/updates.aspx).

8. Conclusions

We appreciate the Seed Research funding. It made possible the hiring of 3 research assistants in 2011, a comparison of campus soil temperatures, the piloting of an energy usage survey (and its analysis), and the completion of a 6-minute video based, in part, on more than 2 hours of video interviews with local individuals with in-depth knowledge or experience with GHP.

Ultimately, funds made available through this Seed Research Grant have helped us educate our community about the advantages of GHP and we hope raised the profile of GHP as an efficiency tool for meeting the Valley 25x'25 goals, which include reducing fossil fuel consumption across the Shenandoah Valley.

Acknowledgements

This research was supported in part by the 'Shenandoah Valley as a National Demonstration Project Achieving 25 Percent Renewable Energy by the Year 2025' under U.S. Department of Energy Grant #DE-EE0003100. A portion of this work was financially supported directly by Hartshorn. The views expressed are those of the authors, and do not necessarily reflect those of the sponsors.

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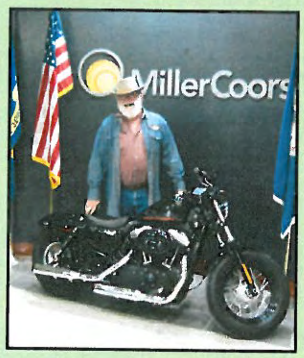
VALLEY
25x'25

VALLEY 25x'25 FALL RESEARCH REVIEW

EMPOWERING OUR COMMUNITY'S FUTURE



Monday, October 10, 2011
ISAT/CS Building, nTelos Room 259
James Madison University

VALLEY 25x'25

Led by James Madison University, Valley 25x'25 promotes using a diverse energy portfolio to achieve 25 percent renewable energy in the Shenandoah Valley before 2025, including wind, biomass, solar, and geothermal energy. A primary emphasis is energy efficiency, which offers the best opportunities to decrease the use and impact of non-renewable energy sources. Endorsed by national 25x'25, Valley 25x'25 serves as an East Coast Demonstration Project, and as such, will be partnering with regional businesses, local and state government, institutions of higher education, and K-12 schools to explore how Valley resources can contribute to the development of innovative energy solutions. A central goal of Valley 25x'25 is to educate and inform Valley residents about renewable energy opportunities. Other goals include advocacy for policies that incentivize and enable renewable energy projects and for streamlining local and state ordinances, building codes, and regulations to facilitate more rapid introduction of new technologies. Encouraging public acceptance and adoption of sensible and environmentally sustainable renewable energy technologies is the single most important contribution we can make toward the long-term prosperity of the region and country.

http://valley25x25.org

INSTITUTE *for* ENERGY *and* ENVIRONMENTAL RESEARCH *at James Madison University*

INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH

The Institute for Energy and Environmental Research (IEER) at James Madison University builds on JMU's recognized leadership in the Commonwealth of Virginia for developing and implementing innovative alternative energy solutions and applied environmental research programs. In addition to working with faculty, staff, and students at JMU, the Institute for Energy and Environmental Research, housed within the Office of the Vice Provost for Research and Public Service, facilitiates strategic alliances with external partners to advance the University's research and service projects. In addition to Valley 25x'25, IEER houses the Virginia Center for Wind Energy and serves as the point of contact for the Virginia Coastal Energy Research Consortium.

http://www.jmu.edu/ieer

CHOOSE ENVIRONMENTAL STEWARDSHIP JAMES MADISON UNIVERSITY

INSTITUTE FOR STEWARDSHIP OF THE NATURAL WORLD

A commitment to being model environmental stewards is one of a handful of characteristics that defines JMU, "The University will be an environmentally literate community whose members think critically and act, individually and collectively, as model stewards of the natural world." The role of the Institute for Stewardship of the Natural World (ISNW) is to facilitate sustainability by coordinating environmental stewardship efforts across campus, advocating for priorities, and challenging all members of the James Madison community to think critically about their role in achieving the long-term stewardship of Earth. The ISNW serves as an internal and external point of contact for university-wide environmental stewardship activities.

http://www.jmu.edu/stewardship

RESEARCH REVIEW **AGENDA**

12:00 p.m.	Introductions	Ken Newbold Director of Research Development
12:05 p.m.	Welcome Remarks	John Noftsinger Vice Provost for Research and Public Service
12:15 p.m.	Valley 25x'25 Overview	Jeffrey Tang Associate Professor of Integrated Science and Technology
12:30 p.m.	Construction and Implementation of a Prolysis Unit for the Production of Biochar in a Sustainable Greenhouse Heating System	Wayne Teel Associate Professor of Integrated Science and Technology
12:55 p.m.	On-Campus GPS Bike Sharing Program	Anthony Teate Professor of Integrated Science and Technology
1:20 p.m.	Valley Geothermal Project	Tony Hartshorn Assistant Professor of Geology and Environmental Science
1:45 p.m.	Harley Davidson Partnership	Chris Bachmann Associate Professor of Integrated Science and Technology
2:00 p.m.	Cultivation of Algae Strains to Produce Oil	Chris Bachmann Associate Professor of Integrated Science and Technology
2:15 p.m.	Break/Refreshments	
2:30 p.m.	Range Estimation of Electric Vehicles Based on Energy Modeling	Robert Prins Assistant Professor of Engineering
2:55 p.m.	Residential Solar Energy in The Valley: A Feasibility Assessment and Carbon Mitigation Poultry, Dairy, and Greenhouses in the Valley: A Technology Assessment of On-Farm Renewable Energy Carbon Mitigation Strategies	Maria Papadakis Professor of Integrated Science and Technology
3:20 p.m.	Materials for Solar Hydrogen Production and Next-Generation Photovoltaic Cells	S. Keith Holland Assistant Professor of Engineering David Lawrence Professor Emeritus of Integrated Science and Technology
3:45 p.m.	Educating and Engaging Local Organizations, Community Members, and University Students through an Energy Efficiency and Sustainable Buildings Community Outreach Program	Carol Hamilton Lecturer of Management
4:15 p.m.	Biodiesel Research and Development Update	Chris Bachmann Associate Professor of Integrated Science and Technology
4:30 p.m.	Closing	Ken Newbold Director of Research Development

PROJECT **DESCRIPTIONS**

Construction and Implementation of a Prolysis Unit for the Production of Biochar in a Sustainable Greenhouse Heating System

Wayne Teel, PI, Associate Professor of ISAT
Julianne Decker, ISAT
Amanda Martindale, ISAT
Dorottya Spolarics, ISAT
Marlee Najamy Winnick, ISAT

Biochar is a form of charcoal made using pyrolysis. This process involves the burning of biomass in the absence of oxygen resulting in a carbon rich, high surface area product. The main byproduct of the pyrolysis process is excess heat that is often unused and released into the atmosphere. Our project involves building an efficient pyrolysis unit and capturing the excess heat. This energy is incorporated into an existing system at Avalon Acres Farm in Broadway, Virginia as a backup method for heating a greenhouse. Their current heating system is powered by solar thermal collectors, which are ineffective during cloudy periods in winter. The overall effect of integrating the two units is a sustainable system. We are currently in Phase I of our project involving the construction of the system. The basic construction of the pyrolysis unit is complete; however the plumbing installation is still underway. Phase II will involve producing and characterizing different forms of biochar from agricultural waste. Types of waste include animal manure, crop residue, and forestry prunings. Our project is likely to lead to future projects within ISAT or Engineering. On a local level, Avalon Acres will reap the majority of the benefits from this project. These benefits include increased soil quality, crop yields and animal health, all of which can be repeated regionally and nationally. At the national scale biochar could prove beneficial to curbing global climate change by improving soil quality, sequestering carbon and providing an alternative energy source. Currently funding must come from the interested parties who wish to build new biochar systems. As the biochar field expands beyond the research phase, an industry will develop yielding more funding possibilities.

On-campus GPS Bike Sharing Program

Anthony Teate, PI, Professor of ISAT
Julianne Decker, ISAT
Dorottya Spolarics, ISAT
Joe Crosbie, ISAT
Renee Parilak, ISAT

The researchers have developed a Prototype GPS Bike-Sharing Program, which includes two bicycles (one for male riders and one for female riders), each outfitted with a GPS-enabled phone which transmits its location, one of the bicycles being additionally outfitted with a bicycle-powered generator to help maintain the cell phone battery charge; a database which logs the bicycles' movements and rider usage; and a website which displays the current location of each bicycle and allows students to register and "check out" a bike online.

The bike-location tracking system was effectively installed and is currently being tested by students on campus, and the data points are actively being stored in a database designed specifically for this project. A website was developed using ASP. NET technology which displays the bicycles' current locations can be viewed by students with access to determine whether the bikes are in use and where they are currently located.

(Continued on page 5)

It is recommended that further research be conducted on additional methods of transmitting the bike locations, and that the project be expanded to be utilized by the general student population at James Madison University.

Valley Geothermal Project

Tony Hartshorn, PI, Assistant Professor of Geology & Environmental Science
Jeremiah Vallotton, Environmental Science
Fernando Perez, Writing, Rhetoric, and Technical Comm.

In Spring 2011, Tony Hartshorn, an Assistant Professor with the Department of Geology & Environmental Science at JMU, received ~$9,000 as Seed Research Funding from Valley 25x'25 to promote the use of geothermal heat pumps (GHP).

GHP is an energy efficiency approach that can dramatically reduce energy consumption associated with heating and cooling buildings, from residential to commercial applications. They should not be confused with geothermal sources of electricity, which are industrial-scale operations that tap the heat of the Earth to generate steam, which is used, in turn, to produce electricity.

As part of this project, the VGP team (Hartshorn and three research assistants: Jeremiah Vallotton, Fernando Perez, and Liz Weisbrot) decided to distinguish between these two geothermal facets of our lives by using a lowercase "geothermal" for the energy-efficient heat pump and uppercase "Geothermal" for the electrical generation complexes. This project focused exclusively on the former.

There were three deliverables from the VGP.

1. We generated a web-accessible soil temperature dataset with standalone dataloggers. Users can compare soil temperatures across 5 campuses (from south to north): Roanoke College, Washington & Lee University, Virginia Tech.'s McCormick Farm (Raphine, VA), JMU, and Shenandoah University.

Our results suggest that JMU has the warmest summer soil temperatures of all five locations, an unexpected result given its relatively high elevation (~1300 feet): air temperatures, and by extension soil temperatures, are generally cooler with increasing elevation. One factor that may compound comparisons between campuses, and helps explain JMU's relatively warm soils, is that the installation site for JMU needed to be adjacent to a paved surface, and the 25-foot-wide service road next to the soil temperature probes most likely creates an artefactually warmer set of conditions during the summer months.

2. The VGP team also assembled energy usage statistics on a voluntary basis from 25 Valley residents. These houses represented a spectrum from multi-resident apartments to single person homes, with square footage ranging from 675 to 5000 ft^2, and with a variety of energy systems (including GHP, HVAC, space heating, fossil-fuel based heater, and others). These data were collected with the intention of examining how electrical usage changed following installation of a GHP, as this would provide a real-world example of energy savings specific to a Shenandoah Valley installation.

(Continued on page 6)

Unfortunately, several individuals with access to GHP clients (who might have been willing to share their electrical usage) were extremely difficult to track down. Nevertheless, we obtained electricity data from two individuals who had monitored electrical consumption before and after their installation of a GHP. In aggregate, these data showed that there is a small decrease in total kilowatt-hours used after the GHP is installed, and then only in the more extreme months in the summer and winter. This suggests that GHP may not be quite as cost-effective as advertisements may claim, although there are still savings, however small, that will continue to accrue for however long utilities are used. As one counterpoint, however, we did meet and interview a JMU staffer who installed his own GHP in his Bridgewater backyard for a total out-of-pocket cost of ~$3000, and with a payback period of <2 years.

3. Finally, the VGP assembled an educational 6-minute video available via YouTube.

Harley Davidson Project

Chris Bachmann, PI, Associate Professor of ISAT
Will Meisne, ISAT
Billy Copely, ISAT
Josh Magura, ISAT
Brent Kiomall, ISAT

The Harley-Davison 2.0 team has worked with a variety of engine platforms and methods for controlling the functionality of these platforms in order to promote a lean-burning, low-polluting and fuel-economic engine. The process began with a prototype Briggs and Stratton engine that was attached to a piece of plywood and monitored for all engine "vital signs" such as intake temperature, crank position, engine temperature, air-to-fuel ration, and rotations per minute. As all of these parameters are vital to the performance of an engine, not only was it necessary to monitor them, but also necessary to control certain parameters responsible for the degree at which the engine performs in a way that is lean-burning and low-polluting – specifically the amount of fuel used during each cycle.

The second step in the team's process was to apply their knowledge of the working systems of an engine on a platform that has a load on the engine. This was accomplished by refitting a carbureted Briggs and Stratton engine that is attached to a "dune-buggy" set-up (to be referred to as the "Baja" from here on) with a fuel-injecting system and all of the necessary sensors. Various options for computational control of fuel dump, such as the use of a MicroSquirt electronic fuel injection (EFI) control system, have been explored. The hardware for this system has repeatedly failed and the team awaits additional hardware.

In that light, progress was started on the Harley-Davidson 48 after the EFI control hardware failed. A system called Power Vision which allows for control of the motorcycle's electronic control module (ECM) was installed to enable modification of the engine performance. During testing of this system and the modification of engine variables responsible for the degree at which the engine performs as lean-burning or low-polluting, the ECM was apparently unresponsive to the modifications made. This was determined by utilizing a dynamometer that showed identical results no matter the adjusts made to the ECM by team members through the Power Vision unit.

(Continued on page 7)

A branch of the team explored options for tuning the engine on a cycle-to-cycle basis by using what is known as an ion current sensor. This system allows for currents produced by the spark plug during ignition to be analyzed and then communicated to the ECM for modification of engine performance. For research purposes and hands on experience, this branch of the team constructed an ion sensor from scratch based upon information publically available from the beginning era of ion sensor development.

As it stands, the team is in progress with their developments due to various obstacles. The future of the project will be centered around effectively controlling the EFI in the Harley and implementing strategies for increased fuel economy, such as turbo-charging, and furthering the underlying goals of a lean-burning and low-polluting end product.

Cultivation of Algae Strains to Produce Oil

Chris Bachmann, PI, Associate Professor of ISAT
Jackson Adolph, ISAT
Mike Depaola, ISAT

Algal biofuels offer a far more comprehensive solution to the problem at hand than any other fuel source. A massive demand will need to be met when petroleum based fuels are finally depleted to the point where they are no longer economically viable. Algal fuels are the only clean renewable option that is truly scalable to the production level of oil. Unlike the production of ethanol or biodiesel from designated crops, competition for land and resources is not a factor when it comes to algal biofuels. Designated energy crops have been known to cause fluctuations in the price of food, destabilizing the market and negatively affecting the farmer and consumer alike. All parties benefit when this type of competition is removed. Algae has the capacity to produce far more fuel per unit area than any designated biodiesel crop. A lack of soil quality depletion is another aspect in which algal fuels reign supreme over designated energy crops simply because they do not require land to grow. The energy input and time commitment required to grow algae are far less than that of a designated energy crop. Most microalgae species have a doubling time of around one week, as opposed to a full season of growth to produce a limited number of harvests per year. The ability to synthesize energy from the Sun is a very large contributor to the success of algal biofuels. The Sun is an infinite, and free, source of energy. Utilization of light energy minimizes costly inputs into the process and thus creates a far more efficient system with a higher net energy gain. Carbon dioxide sequestration is an integral part of this process as well. Due to their simplicity as single celled organisms they are afforded a fast growth rate; because of this microalgae have the unique ability to take in far more CO_2 than any land based plant ever could. The lack of complex structures like root and shoot systems afford as much energy as possible to be put toward cellular division and the production of fat which will be isolated in order to create fuel. Furthermore, algae possess the unique ability to grow in waste streams unfit for most other life and take up nutrients from their environment that may cause harm to the given ecosystem. A carbon neutral process as well as nutrient sequestration is of central importance to recovering from the negative environmental impact created by reliance on fossil fuels. Low energy input, fast growth rate, a lack of competition for resources, carbon neutrality, and positive environmental impacts, paired with nearly limitless potential for growth make algal biofuels a very appealing solution to the question of fuel.

Range Esimation of Electric Vehicles based on Energy Usage Modeling

Robert Prins, PI, Professor of Engineering
Lee Winslow, Geographic Sciences
Robbie Hurlbrink, Engineering

Electric vehicles show significant promise as a viable means of transportation. They use their stored energy more than twice as efficiently as their typical internal combustion engine powered counterparts, and are classified as having zero point of use emissions. While concerns about their ultimate energy source are well founded, they are positioned to take advantage of a wide range of renewable energy sources since many such sources produce electrical energy. One of the largest consumer concerns related to electric vehicles is their perceived lack of range. Although range estimates for particular vehicles are available these estimates are used as a marketing tool and may be unreliable, especially if the vehicles will experience duty cycles that are dissimilar to standard test duty cycles. Speed, load, and topography all play a significant role in the real range of an electric vehicle. Fleet managers and other potential owners do not have a reliable way to estimate vehicle range prior to purchase and operation. The current approach to range modeling is typically based on fixed duty cycles such as SAE J1711 or Federal Urban Driving Schedules. While such duty cycles provide valuable comparative data they do not typically correlate to the real duty cycle that a particular vehicle is subject to. This can lead to unrealistic expectations of electric vehicle range and the associated "buyer's remorse" at having invested in an emerging technology when the anticipated performance is not achieved. This proposal seeks to further develop a novel energy usage modeling approach that could be applied by fleet managers and other owners to help them make appropriate decisions regarding electric vehicle deployment.

Residential Solar Energy in The Valley: A Feasibility Assessment and Carbon Mitigation

Maria Papadakis, PI, Professor of ISAT
Deanna Zimmerman, SERM/MSISAT

This project explores whether the Shenandoah Valley can achieve its 25x'25 goals in the residential sector using the two most feasible solar energy technologies, solar photovoltaic electric power production and solar thermal hot water generation. After a review of the barriers to the adoption of solar energy by households, we estimate the potential rates of adoption and energy output using US Census data and Department of Energy data. Multiple scenarios are explored, including the "maximum theoretical" contribution of solar energy to the residential sector as well as scenarios of household behavior under different constraints. With respect to solar photovoltaic, we argue that the "most likely" theoretical scenario is one in which about 21% of Valley households adopt a 1-kilowatt system. If that was so, then solar photovoltaic electricity would contribute less than 3% of the residential sector's total energy needs in the Shenandoah Valley. The associated carbon mitigation is equivalent to about 8200 passenger vehicles.

PROJECT **DESCRIPTIONS**

Poultry, Dairy, and Greenhouses in the Valley: A Technology Assessment of On-Farm Renewable Energy Carbon Mitigation Strategies

Maria Papadakis, PI, Professor of ISAT
Laura Kossey, SERM/MSISAT

This project explores whether the Shenandoah Valley can achieve its 25x'25 goals in energy-intensive farms in the agricultural sector, which are primarily poultry, dairy, and greenhouse operations. We assess the two most feasible renewable energy technologies for such farms, solar photovoltaic electric power production and wind power. After a review of the barriers to the adoption of renewable energy by agricultural operations, we estimate the potential rates of adoption and energy output using US data from the US Census of Agriculture, pilot farm energy audits, the Department of Energy, and the Virginia Renewables Siting Scoring System. Multiple scenarios are explored, including the "maximum theoretical" contribution of renewable energy to the agricultural sector as well as scenarios of farm behavior under different constraints. We find that the payback period for these technologies typically exceed 30 years, well beyond the agricultural sector's preferred payback period for comparable investments of 3-5 years or less.

Materials for Solar Hydrogen Production and Next-Generation Photovoltaic Cells

S. Keith Holland, Assistant Professor of Engineering
David Lawrence, Professor Emeritus of ISAT

Widespread, large-scale use of solar energy requires methods to efficiently convert light energy into electrical energy. Further, methods for converting captured solar energy into a fuel, such as hydrogen, for use when sunlight is not available and/or for transportation applications are needed. Hydrogen gas can be obtained through photoelectrolysis by illuminating photosensitive semiconductor materials immersed in an electrolyte solution. To date, suitable, low-cost, chemically stable materials for photoelectrolysis have not been developed. However, there is significant interest in doped BiVO4 and CZTS thin films for photoelectrolysis and next-generation PV cells.

Based on substantial theoretical work, National Renewable Energy Laboratory (NREL) researchers recently concluded that the addition of dopants such as Ca, Na, and K to BiVO4 thin films should produce excellent p-type semiconductor properties and conductivity. This work also concluded that Mo and W doping of BiVO4 should result in excellent n-type conductivity. Such enhanced electrical conductivity is expected to lead to enhanced hydrogen production efficiencies in photoelectrochemical (PEC) cells. Additionally, if BiVO4 with sufficiently high p-type and n-type conductivities can be prepared, this material may also be used as tunnel junction material for next-generation multi-junction photovoltaic (PV) cells.

This investigation examined the effects of specific dopants on the electrical and PEC water splitting performance of BiVO4. Doped thin-film BiVO4 samples were prepared from a variety of different chemical precursors using a spray pyrolysis technique, a relatively low-cost technique that could be scaled for high volume production, followed by annealing. The morphology, chemical consumption, and crystallinity of the prepared BiVO4 films were analyzed using scanning electron

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microscopy, UV/VIS spectroscopy, and x-ray diffractometry. Electrical conductivity and PEC performance tests were also performed on the samples.

Results of this investigation demonstrated that doped $BiVO_4$ thin-films can be created using the spray pyrolysis deposition technique. Chemical precursors and additives greatly influenced by the morphology of the produced thin-films; however, the morphology of the thin films were not significantly impacted by the inclusion of dopants. Films deposited from precursors containing ethylene glycol and EDTA resulted in thinner, smoother films which provided higher optical transmittance for wavelengths greater than 500 nm, a characteristic desirable for next-generation PV cell tunnel junction materials. Consistent with the NREL theoretical predictions, the addition of Mo and W dopants resulted in n-type behavior which the addition of Ca dopants indicated p-type behavior when tested in the PEC cell. W doped samples annealed in 3% H_2 generated the highest photocurrent densities during PEC testing. However, high material conductivity was not achieved in any of the samples produced.

Future work will focus on increasing the conductivity of the $BiVO_4$ samples through the selection of precursor chemicals and dopants. Additionally, work on CTZS thin film materials is proposed.

Educating and Engaging Local Organizations, Communitity Members, and University Students through an Energy Efficieny and Sustainable Buildings Community Outreach Campaign

Carol Hamilton, PI, Lecturer of Management
Daniel Hill, MBA
David Hussey, MBA

The Valley 25x'25 funded project, "Educating and Engaging Local Organizations, Community Members, and University Students thru an Energy Efficiency and Sustainable Buildings Community Outreach Program" has developed a fully operational community outreach project that is currently being implemented in the Shenandoah Valley and other communities. The project, Green Impact Campaign, connects students with local businesses as a way to recognize tangible energy efficiency opportunities within organizations through public recognition and free energy services.

Green Impact Campaign (www.greenimpactcampaign.com) is an innovative training program that allows students to perform energy audits for local businesses in their community. The program is centered around a web-based platform that requires no previous energy auditing knowledge and allows students to complete a full energy audit in less than one hour, all while receiving energy audit experience. The web-based, mobile accessible program, GEMS (gems.greenimpactcentral.com), is a self-training energy audit tool that guides student volunteers through a facility identifying lighting, plug load, HVAC, building envelope and water energy conservation measures (ECMs). Based on user input, GEMS then references a catalog of ECMs, calculates energy saving estimates and compiles a report that is then sent to the participating business. Through this process, local businesses receive free energy efficiency advice, students gain real world hands on green job experience, and both are working to make a positive impact on the planet.

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For any organization or business that is interested in having a free energy audit performed, they are required to take a sustainability oath called the Green Impact Pledge. The Pledge is an online, public oath that confirms that the organization is interested in reducing its environmental impact and they plan to take action in implementing changes. Any organization who takes the Pledge is then promoted to the community as an active organization who is concerned with environmental sustainability.

Net Impact has entered into a partnership with Green Impact Campaign to offer the project as a sponsored project to its network of student chapters. As of this report's creation, twenty student Net Impact chapters have agreed to implement Green Impact Campaign in their community. Twelve businesses have taken the Green Impact Pledge and four have received energy audits. In total, 22,258 kWh of energy reductions have been discovered during the energy audits. Green Impact Campaign won the 2011 Force for Change Award for its positive environmental and social impact through its use of grassroots efforts.

In the future, the project will be improved and further developed in several ways. First, the follow up process for businesses that have received energy audits will be more comprehensive. Second, further refinements to the GEMS program will be made to improve the accuracy of estimates and additional unit conversions. Third, GEMS' project management features will be further expanded by adding a service provider directory and an ECM/utility tracker. Fourth, additional audit topics will be replicated using the GEMS energy audit methodology.

Biodiesel Research and Development

Chris Bachmann, PI, Associate Professor of ISAT
Scott Teigeler, ISAT
Jeff Wiggins, ISAT
Bernard Newman, Chemistry

Our project focuses on the incorporation of biodiesel as a key fuel source for the U.S and the ability for farmers to complete it on a small to medium scale. Currently biodiesel processors on the small scale are not cost effective and do not ensure the product produced will meet with ASTM standards for commercially viable biodiesel. Our goal is to discover a solid-state catalyst that will enable a more cost effective and reliable process for small to mid sized biodiesel processors. Currently much of the canola that is grown in the Shenandoah Valley is shipped across the state to be pressed and have the oil extracted, then the dry grains returned as feed. If there was a viable mid-scale biodiesel processor that could produce quality fuel reliably, there could be a market in the area for farmers to start to press and use the oil themselves. This would give another opportunity for farmers to make money on another aspect of their harvest as well as providing the valley with an opportunity to use more renewable fuels.

MEET THE **VALLEY 25x'25 TEAM**

John Noftsinger	Principal Investigator, Vice Provost for Research and Public Service
Kenneth Newbold	co-PI, Director of Research Development
Chris Bachmann	co-PI, Associate Professor of Integrated Science and Technology
Jeffrey Tang	co-PI, Associate Professor of Integrated Science and Technology
Benjamin Delp	Associate Director of Research Development
Becky Rohlf	Fiscal Technician for Research and Public Service
Craig Honeycutt	Valley 25x'25 Outreach Coordinator
Nathan Miller	Valley 25x'25 Research Assistant
Elise Lintelman	Valley 25x'25 Research Assistant
Garrett Stern	Valley 25x'25 Research Assistant
Sallie Drumheller	Print Production Assistant for Research and Public Service

The Valley 25x'25 Fall Research Review is a half-day event featuring presentations from student, faculty, and staff researchers whose projects received funding during the summer of 2011. The Research Review provides a venue for interested community members to hear about the challenges, successes, and recommendations from a variety of different research endeavors. Valley 25x'25 funding comes from a generous grant from Senators Warner and Webb, DE-EE0003100 "Shenandoah Valley as a National Demonstration Project Achieving 25 Percent Renewable Energy by the Year 2025 (VA)," which is administered through the U.S. Department of Energy.

For more information, please visit our website at **Valley25x25.org**

JAMES MADISON UNIVERSITY

JMU RESEARCH AND PUBLIC SERVICE

VALLEY 25x'25
FALL RESEARCH REVIEW

EMPOWERING OUR
COMMUNITY'S FUTURE

Wednesday, October 24, 2012
ISAT/CS Building, nTelos Room 259
James Madison University

VALLEY 25x'25

Led by James Madison University, Valley 25x'25 promotes using a diverse energy portfolio to achieve 25 percent renewable energy in the Shenandoah Valley before 2025, including wind, biomass, solar, and geothermal energy. A primary emphasis is energy efficiency, which offers the best opportunities to decrease the use and impact of non-renewable energy sources. Endorsed by national 25x'25, Valley 25x'25 serves as an East Coast Demonstration Project, and as such, is partnering with regional businesses, local and state government, institutions of higher education, and K-12 schools to explore how Valley resources can contribute to the development of innovative energy solutions. A central goal of Valley 25x'25 is to educate and inform Valley residents about renewable energy opportunities. Other goals include advocacy for policies that incentivize and enable renewable energy projects and for streamlining local and state ordinances, building codes, and regulations to facilitate more rapid introduction of new technologies. Encouraging public acceptance and adoption of sensible and environmentally sustainable renewable energy technologies is the single most important contribution we can make toward the long-term prosperity of the region and country.

http://valley25x25.org

INSTITUTE *for* ENERGY *and* ENVIRONMENTAL RESEARCH *at James Madison University*

INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH

The Institute for Energy and Environmental Research (IEER) at James Madison University builds on JMU's recognized leadership in the Commonwealth of Virginia for developing and implementing innovative alternative energy solutions and applied environmental research programs. In addition to working with faculty, staff, and students at JMU, the Institute for Energy and Environmental Research, housed within the Office of the Vice Provost for Research and Public Service, facilitates strategic alliances with external partners to advance the University's research and service projects. In addition to Valley 25x'25, IEER houses the Virginia Center for Wind Energy and serves as the point of contact for the Virginia Coastal Energy Research Consortium.

http://www.jmu.edu/ieer

OFFICE OF ENVIRONMENTAL STEWARDSHIP AND SUSTAINABILITY

A commitment to being model environmental stewards is one of a handful of characteristics that defines JMU, "The University will be an environmentally literate community whose members think critically and act, individually and collectively, as model stewards of the natural world." The role of the Office of Environmental Stewardship and Sustainability (OESS) is to facilitate sustainability by coordinating environmental stewardship efforts across campus, advocating for priorities, and challenging all members of the James Madison community to think critically about their role in achieving the long-term stewardship of Earth. The OESS serves as an internal and external point of contact for university-wide environmental stewardship activities.

http://www.jmu.edu/stewardship

RESEARCH REVIEW **AGENDA**

12:00 p.m.	Welcome Remarks	Kenneth Newbold Director of Research and Innovation Jeffrey Tang Associate Professor of Integrated Science and Technology
12:15 p.m.	Shenandoah Agricultural Products	Parker Helble Student of Engineering
12:30 p.m.	Algae as a Biofuel	Caleb Talbot Student of Integrated Science and Technology
12:45 p.m.	Biodiesel Gas Chromatography	Jonathan Hawkins Student of Integrated Science and Technology Jason McNamara Student of Integrated Science and Technology
1:00 p.m.	Sustainability Assessment Matrix	Adebayo Ogundipe Assistant Professor of Engineering
1:30 p.m.	Renewable EV Conversion	Alleyn Harned Executive Director of Virginia Clean Cities
2:00 p.m.	Defining the 25% Goal for Valley 25x'25	Brian Becker Bioenergy Consultant at Conserv
2:30 p.m.	Break	Refreshments
2:45 p.m.	Wholesome Energy Water/Fuel Emulsifier	Joe Crosbie Student of Integrated Science and Technology
3:00 p.m.	Two-Phase Energy System	Jacquelyn Nagel Assistant Professor of Engineering
3:30 p.m.	Nutrient Trading and TMDLs: Implications for Renewable Energy in the Shenandoah Valley	James Sheats Student of Integrated Science and Technology
3:45 p.m.	The Energy Challenge	Karim Altaii Professor of Integrated Science and Technology
4:15 p.m.	Closing	

PROJECT **DESCRIPTIONS**

SHENANDOAH AGRICULTURAL PRODUCTS

Parker Helble, Engineering

Shenandoah Agricultural Products is a company based in Clear Brook, Virginia, consisting of a small group of farmers who grow, crush and sell their own canola oil (along with other agricultural products). Not only do they produce and distribute canola oil, but they also collect waste oil from restaurants to convert into biodiesel fuel that is then used to power farm equipment.

The project focused on analyzing the current biodiesel production system from a safety standpoint and making realistic recommendations that could be easily implemented. Another important task was to update the production procedure and testing manual: there were many handwritten notes that were crucial to proper testing methods that needed to be incorporated into the manual. Additionally, a complete visual accompaniment for the procedure for future employee reference was provided. Furthermore, a multivariable procedure to test an apparatus to reintroduce a byproduct into the pretreatment process was designed to improve biodiesel yield and reduce production costs. Finally, an analysis of ASTM testing for B100 biofuel was conducted and provided insight to the economic feasibility of purchasing testing equipment for the facility.

ALGAE AS A BIOFUEL

Caleb Talbot, ISAT

Algae-based biofuels have received increasing attention as an alternative to petroleum products because of their potential to provide clean, renewable energy on a global scale. However, efforts to commercialize algae-based biofuels have failed because they have not been cost-competitive with traditional gasoline and diesel fuels. One of the main challenges in developing a cost-competitive, algae-based biofuel is effective separation of algae from the growth medium. The purpose of this study is to compare several different algae-harvesting strategies that could be applied to large-scale, offshore algae cultivation.

Indoor and outdoor algae cultivation systems were established to provide abundant algae resources for the harvesting experiments. Nannochloropsis micro-algae were selected because of their high oil content and ability to grow rapidly in ocean environments. Once algae cultures were established, various harvesting strategies were tested for their ability to remove algae from the water. Preliminary experiments involving centrifugation, sonication, ultraviolet exposure, hydro-cyclone separation, electro-flocculation and solvent-medium emulsification showed that algae could be purified effectively. Electro-flocculation and solvent-medium emulsification were most promising and merit further studies. Current work is now focusing on a more comprehensive, quantitative comparison of these two algae-harvesting strategies, with particular emphasis being given to percentage of algae collected, energy input versus output, scale-up potential and economic feasibility.

PROJECT **DESCRIPTIONS**

BIODIESEL GAS CHROMATOGRAPHY

Jonathan Hawkins, ISAT
Jason McNamara, ISAT

Biodiesel is a clean-burning, renewable fuel with significant potential for the Shenandoah Valley. It can be made from a wide variety of naturally-occurring vegetable oils and purified cooking oil waste. Currently, there are three small-scale biodiesel startup companies that are hoping to produce biodiesel from locally-grown agricultural products and regionally supplied waste-cooking oils. One challenge for these startup companies is to produce biodiesel that meets or exceeds ASTM specifications for biodiesel.

The purpose of this project was to establish Gas Chromatography (GC) analysis, according to ASTM specifications, and to apply the analysis in support of these three local biodiesel startup operations. To accomplish this, a Hewlett-Packard 5890 GC was outfitted with an Agilent CP9078 column for biodiesel analysis. Standard calibrations curves were prepared in accordance with the ASTM D8635 Standard for Free and Total Glycerol Content. R-squared values were determined to be 0.98, 0.98, 0.93, and 0.95 for glycerol, monoolein, diolein, and trioolein respectively, indicating that the system is calibrated and functioning properly. These reference curves can now be applied to determining the overall quality of biodiesel, enabling JMU to provide a less expensive fuel quality analysis to local producers during the startup phase of operation when a high-level of adjustments and calibrations are anticipated. In addition, in-house GC analysis will also support research at JMU into solid-phase biodiesel catalysts and nonconventional production strategies aimed at reducing production costs.

SUSTAINABILITY ASSESSMENT MATRIX

Adebayo Ogundipe
Assistant Professor of Engineering

Production of poultry and poultry products results in the generation of massive amounts of litter, a mixture of feces, feed, feathers and bedding materials such as straw, peanut or rice hulls, and wood shavings. Following removal from poultry production facilities, litter is commonly applied to pastures and hay meadows to increase forage production and quality. However, repeated applications of poultry litter can lead to accumulations of Nitrogen and Phosphorous in soil as well as elevated levels of one or both of these nutrients in surface runoff and subsurface water. This form of disposal of waste from the poultry industry, and the subsequent environmental implications, has stimulated interest in alternative disposal options.

There have been studies reporting the feasibility of using poultry litter as an alternative natural fuel source for power generation. While the process may appear to be a viable energy source with certain environmental benefits, this does not automatically imply that the overall system is sustainable. Decisions on

(Continued on page 6)

new practices and technologies are currently and typically based on the perceived "greenness" of the method or technology itself, but the overall impact of all auxiliary operations as well the issues associated with risk transfer, socio-cultural acceptability and local micro-economics are typically not considered.

This project investigated the development of an assessment tool to be used in the comparative analysis of the sustainability of the various alternatives of poultry litter disposal, particularly poultry litter to energy technologies. A fundamental driver to this issue is that there are currently no standards or metrics for sustainable development practices. Likewise, there has been no common guidance or framework to assure any standardization in the integration, architecture, and development of sustainable development practices. The process for the development of a Sustainability Assessment Matrix (SAM) to be used as a tool to guide the objective and systematized assessment of the economic, environmental and social impacts associated with current and proposed systems will be presented. This tool will allow for the comparison of overall systems as well as guide the decision of choices within subsystems. Overall, the objective is to facilitate development in the direction of true – and not merely perceived – sustainability.

RENEWEABLE EV CONVERSION

Alleyn Harned
Executive Director of Virginia Clean Cities

For this project, the team set out to transition a full-sized passenger hybrid electric vehicle from an imported fossil petroleum fuel source to a greater blend of renewable electricity as a fuel resource. This shows reduction of fossil energy consumption in the transportation sector through a demonstration of plug-in modification and increasing fuel efficiency with a common model Toyota Prius, beginning the transition from petroleum fuel to energy supported by locally generated solar or wind systems. First, a plug-in conversion technology was applied to the vehicle (the first of its kind in the Valley), and secondly, renewable fuel systems were tested in order to illustrate clean refueling options.

Transportation represents a significant energy sector in the Commonwealth, generally from nonrenewable and often non-domestic sources. Overall, 25% of our state's energy usage comes from this sector, and nearly all of that energy now comes from fossil petroleum. Without statistically significant in-state production of the fuel, or of renewable components such as ethanol, Virginia is a major consumer of OPP: Other People's Petroleum. As we produce other energies and possess renewable resources, transportation alternatives represent a key method to reach the Valley's 25x'25 goal.

This effort represents transportation and an alternative fuel vehicle project, as well as supporting partnerships with local industry partners such as Sunrnr and connections with the local and regional communities. Before and after tracking data was collected and incorporated into a case study, and the vehicle demonstrations were provided. Equipment was provided by JMU staff of Virginia Clean Cities.

DEFINING THE 25% GOAL FOR VALLEY 25 X '25: Energy Inventory of the Shenandoah Valley

Brian Becker
Bioenergy Consultant at Conserv

The goal of Valley 25x'25 is to see 25% renewable energy in the Shenandoah Valley by the year 2025. Quantifying current energy production and consumption in the Valley is the first step in defining the 2025 target. This presentation reports on progress of the energy inventory to date. Initial estimates were derived from state-level, publically available population data. Production and consumption are stratified by energy source (electricity, coal, petroleum products, natural gas and renewable) and consumption sector (residential, commercial, industrial and transportation). Longer-term efforts are underway to source primary data directly from energy service providers. The inventory process will also serve to identify potential partners and engage stakeholders who will be an integral part of the Valley 25x'25 efforts. This first-of-its-kind energy inventory of the Shenandoah Valley will be the initial step in developing a strategic energy plan for how the residents of the Shenandoah Valley will achieve 25% renewable energy by the year 2025.

WHOLESOME ENERGY WATER/FUEL EMULSIFIER

Joe Crosbie, ISAT

Exhaust emissions from internal combustion engines have been gaining increased attention as a significant source of environmental pollution. Water-injection has been put forward as a means of reducing exhaust emissions, especially in diesel engines, but has required extensive engine modifications and high installation costs. The purpose of this study was to evaluate the effectiveness of a novel device being marketed by Wholesome Energy of Edinburg, VA, which claims to reduce emissions and fuel consumption by emulsifying water into vehicle fuel just prior to the injection system. The water-fuel emulsifying device was installed on a 2003 Mack CX600 tractor-trailer cab and tested on a Taylor water-brake dynomometer operating at 192 horsepower at 60 mph. Ten trials with water emulsion were compared to ten trials of straight diesel fuel. Particulate matter was reduced 50% (opacity and mass, $p<0.001$) and CO fell by 48% ($p<0.001$). These results indicate that significant environmental benefits could be achieved by using this device on diesel engines.

Further tests using a gasoline-powered engine are currently underway to provide more conclusive results regarding fuel consumption and a full range of exhaust gas emissions, particularly nitrogen oxides (NOx). The device is easily installed and does not require significant engine modifications. It is also easily scalable. Therefore, this device could potentially be used on a wide range of vehicle fleets, including trucks, trains, buses, ships and construction equipment to reduce harmful particulate matter and exhaust gas emissions.

PROJECT **DESCRIPTIONS**

TWO-PHASE ENERGY SYSTEM

Jacquelyn Nagel
Assistant Professor of Engineering

The research objective of the two-phase energy system is to explore the technical challenge of sustainability as it relates to solar energy production, storage and consumption. A fundamental approach to decreasing the environmental impact of a solar energy system is to reduce the toxic – non-recyclable and recyclable – materials within, and maximize the lifetime of each component to reduce waste. This project focused on the design of a clean, renewable energy system for residential use, with the goal of providing electrical energy during both day and night without the use of chemical batteries.

A traditional photovoltaic solar system that collects light from the sun to produce electrical energy comprises the first phase. Phase two aims to replace the traditional battery bank found in solar energy systems with a fluid-mechanical energy system design that stores potential energy as a liquid. The gravity fed release of a stored liquid during the lunar cycle is used to generate energy. The desired output is 12 VDC to match the capabilities of a chemical battery. Over 15 concepts for energy generation during the lunar cycle were created. Four concepts based on the strategies of rotation, momentum, impact and return, and pressure difference were chosen for further exploration to assess feasibility of the ideas. Prototypes for the rotation and momentum concepts were constructed and tested. Additionally, all individual system components were tested and validated before the entire system was contracted.

A scaled-down version of the two-phase system with the rotational energy generation strategy was constructed, as well as a traditional solar energy system with a battery for comparison. System wiring meets electrical code standards and safety guidelines. Additionally, both systems are built on mobile platforms so each can operate under similar sun conditions. Preliminary results of the rotational energy generation strategy for the lunar phase produced about 4 VDC. Energy is lost to sources of mechanical friction, and height of the stored liquid was constrained to keep the system mobile. Future tests will vary the stored liquid height and capacity as well as the energy generation mechanism. Further analysis and prototyping of the two-phase energy system will be undertaken as a two-year engineering capstone project.

NUTRIENT TRADING AND TMDLS: Implications for Renewable Energy in the Shenandoah Valley

James Sheats, ISAT

Recently, increased attention has been paid to water quality issues that plague the Chesapeake Bay and the implications for its watershed. In 2009, President Obama signed an executive order establishing a new sense of urgency in protecting and restoring the bay and in late 2010 the EPA instituted the Bay Total Maximum Daily Loads (TMDLs). This effectively set pollution limits necessary to meet requirements of the Clean Water Act. The responsibility of meeting TMDL limits falls to the states, requiring each to implement pollution reduction controls. In the Shenandoah Valley, a major concern is nutrient runoff from the various agricultural operations, especially those involving livestock. Rockingham County is one of the largest turkey producers in the nation and is the most productive chicken and dairy-producing county in the Commonwealth. In order to manage these excess nutrients, some states, including Virginia, are looking into nutrient trading programs.

This project analyzes the history of Chesapeake Bay pollution management, the effect of agriculture on the water quality of the Shenandoah Valley, and political climates in order to determine the practicality of establishing a nutrient trading program, including nonpoint sources in the region. Thus far, research that is critical in the formation of appropriate survey questions, as well as the positive and negative consequences of program implementation, has been fathered on the history and fundamental principles of nutrient trading programs. Much of the subsequent research will involve surveys and interviews with farmers, organizations, and other stakeholders to illuminate perspectives essential to the success or failure of a trading program. This analysis will have direct implications for potential litter-to-energy systems in the Valley, as the conditions of TMDLs and trading programs will affect their economic feasibility.

THE ENERGY CHALLENGE

Karim Altaii
Professor of ISAT
Eric Rothschild (Lead), ISAT
Andy Duong, ISAT
Morgan Mason, ISAT
Ryan Sheppard, ISAT
Davud Stevens, ISAT

JMU 101 - The Energy Challenge - is a course that will enable JMU students to understand global and national energy usages with a primary emphasis on the residential energy sector. The course will also focus on educating students about the necessary efficiency, technology and conservation changes needed to sustain the current high energy demands for future generations. This approach will provide students a global consciousness that will influence students' performances in their other courses throughout their JMU careers, regardless of major. In return, students will be able to apply what they learn to develop seenior projects or conservation programs to improve JMU, their homes, and their communities.

Course curriculum has been designed and developed and will be taught in the spring of 2013 by students under the supervision of faculty members in order to maximize a collaborative effort between the student body, faculty, and administration. The material will be delivered in the classroom via lectures from instructors, videos for recitations, presentations from business owners and other credible sources within the residential energy industry to induce "real world" knowledge and networking opportunities. In order to make sure the knowledge gained in the classroom is retained and applicable, the material will be tested via laboratory experiments that will reinforce concepts learned in the classroom. The Energy Challenge will assign activities that will challenge students to come up with ideas to conserve energy on a personal level and share them with other students in order to spread the knowledge gained from the classroom as effectively as possible.

VALLEY 25X'25 OUTREACH EVENT **IN FOCUS**

Valley 25x'25 partners with Firestone and Virginia Clean Cities to host Tire Pressure Awareness Event

James Madison University hosts an array of programs focusing on renewable and alternative energy specific to the transportation sector. Two of these entities – Valley 25x'25, an outreach program seeking to increase renewable energy usage in the Shenandoah Valley; and Virginia Clean Cities, a coalition program seeking to increase the use and availability of domestic, clean burning fuels – partnered with Firestone Complete Auto Care of Harrisonburg on August 30th to educate vehicle owners on the importance of maintaining proper tire pressure. Approximately 25 individuals visited Firestone for a tire pressure check-up, in addition to an informal tutorial on tips to improve vehicle fuel economy by Valley 25x'25, Firestone, and Virginia Clean Cities staff.

The Valley 25x'25 program focuses on cost-effective solutions to increase energy efficiency and in the process save money for Valley citizens. The tire pressure awareness event addressed this goal directly, as the EPA estimates a 3% decrease in fuel economy for every 1 psi of underinflation in all four tires. This could amount to hundreds of dollars wasted each year. Event participants received a handout of a chart detailing the costs associated with underinflated tires for multiple advertised fuel economies. On the other end of the spectrum, overinflated tires create a bulge in the middle portion of a tire, leading to uneven wear, which can decrease the life of a tire by thousands of miles. Tire pressures should be checked monthly. Recommended inflation pressures are listed on the driver's side door jamb or in the owner's manual.

Virginia Clean Cities and the U.S. Department of Energy recommend the following additional tips to improve fuel economy on the road:

1. Drive sensibly – Up to a 33% improvement in highway fuel economy can be realized by changing aggressive driving habits.
2. On the highway, you can assume that with each 5 mph you drive over 60 mph your fuel economy drops by 5%. When you drive 75 mph vs. 55 mph it's like burning an extra gallon of fuel every 100 miles traveled.
3. Several short trips, all starting with a cold start, can use twice as much fuel as one trip with several stops and may cause you to travel more miles. Plan your trips efficiently.

A major goal of Valley 25x'25 is outreach and engagement activities that educate the community on energy efficiency and renewable energy options. A similar service was provided at the 2012 Harrisonburg Clean Energy Odyssey Day, which was held on October 18th at the Turner Pavilion in downtown Harrisonburg.

For more information about this event, please contact Ben Delp (delpbt@jmu.edu).

THE VALLEY 25x'25 **TEAM**

Kenneth Newbold	PI, Director of Research and Innovation
Chris Bachmann	co-PI, Associate Professor of Integrated Science and Technology
Jeffrey Tang	co-PI, Associate Professor of Integrated Science and Technology
Benjamin Delp	Associate Director of Research Development
Becky Rohlf	Fiscal Technician for Research and Public Service
Craig Honeycutt	Valley 25x'25 Outreach Coordinator
Sallie Drumheller	Print Production Assistant for Research and Public Service

WHY THE **SHENANDOAH VALLEY?**

The Shenandoah Valley is well suited to serve as a demonstration region for attaining the 25x'25 vision. Historic and renowned for its beauty, the Shenandoah Valley is truly an all-American region with a diverse environment and varied resources, including:

- An agricultural base and tradition of small-scale farming
- A location in the middle of the East Coast, just a short drive from policymakers in D.C.
- 11 colleges and universities, including James Madison University, with a proven track record in community outreach and practical renewable energy research

The Valley 25x'25 Fall Research Review is a half-day event featuring presentations from student, faculty, and staff researchers whose projects received funding during the summer of 2012. The Research Review provides a venue for interested community members to hear about the challenges, successes, and recommendations from a variety of different research endeavors. Valley 25x'25 funding comes from a generous grant from Senators Warner and Webb, DE-EE0003100 "Shenandoah Valley as a National Demonstration Project Achieving 25 Percent Renewable Energy by the Year 2025 (VA)," which is administered through the U.S. Department of Energy.

For more information, please visit our website at Valley25x25.org

JAMES MADISON UNIVERSITY

JMU RESEARCH AND PUBLIC SERVICE

GSCI 101 – The Energy Challenge
Mid-term Report

Project Funded by Valley25x'25 and IEER

Principal Investigator: ***Karim Altaii****
Co-Principal Investigator: ***Eric Rothschild (Lead), Andy Duong, Morgan Mason, Ryan Sheppard, David Stevens****
October 1, 2012

Executive Summary

James Madison University (JMU) strives to be a model of environmental stewardship with numerous activities reinforcing that commitment. However, there are no courses accessible to *all* majors that address our behavior and attitudes towards energy use and the associated consequences. Although the energy debate focuses on rethinking sources of energy, we also as a society need to think about how we consume energy. Out of the four major sectors, the residential energy sector is most influenced by the public because it is heavily reliant on energy maintenance and consumption patterns. This course will educate students about the ongoing energy crisis and present various conservation techniques with strong emphasis on energy consumption within the residential sector. In return, students' friends and families will absorb this knowledge and help accelerate the effort and change needed to tackle the energy crisis. If successful, this class can be expanded to reach a younger educational audience and adults in our community. This class will enable a more diverse understanding for those who may not major in science and technology.

GSCI 101 - *The Energy Challenge*, is a course that will enable students to understand the global and national energy usages with a primary emphasis on the residential energy sector. The course will also focus on educating the students about the necessary efficiency, technology, and conservation changes needed to sustain the current high energy demands for future generations. This approach will provide students a global consciousness which will influence students' performances in their other courses throughout their JMU careers regardless of their major. In return, students will be able to apply what they learn to develop senior projects, or conservation programs to improve JMU, their homes, and their communities.

The course curriculum has been designed, developed and will be taught by a team of ISAT undergraduate students under the supervision of Dr. Karim Altaii. The material will be delivered in the classroom via lectures, videos, labs, recitation, and tours from professors, business owners, and other professionals within the residential energy industry. In order to make sure the knowledge gained in the classroom is retained and applicable, the material will be tested via laboratory experiments and three exams that will reinforce concepts learned in the classroom.

The course has been developing since January 2012 and during the summer of 2012 months, the student researchers have been able to design and create all the homework assignments, lectures, recitations, exams, and student surveys necessary for *The Energy Challenge* to make a true impact. The course will be offered in spring of 2013 in order to solidify not only the lecture techniques, but also the lecturer's style of teaching to make sure that the information reaches the students in the most absorbable ways possible.

* The work that follows is a students' initiated, proposed and delivered work. The faculty member (Dr. Karim Altaii) is the advisor, a facilitator and a coordinator and to assure that the proposed work will be delivered.
**All Co-Principal Investigators listed above are undergraduate students in the ISAT Department.

Project Results & Deliverables

A blackboard site has been created for *GSCI 101: The Energy Challenge*. This is the location which all the deliverables are located including lectures, recorded lectures, homework assignments, homework solutions, laboratory assignments, recitations, and exams.

Products

- Course syllabus
- 30 Lectures (2 lectures per week)
- 8 Recitations
- 3 Laboratory Assignments
- 14 Homework Assignments
- 3 Exams
- 2 Student Surveys

Project Contributions to Community

JMU has never offered a General Education course that is entirely student derived and almost entirely student taught. This ensures that students will not only relate to the instructor, but will also relate to the subject matter. This course will also grant students knowledge that can be immediately incorporated into their own lifestyles. These course values will spread throughout the community by observation and word of mouth. Thus, the practices will quickly expand from the classroom to the community. This course will confront the ever-expanding residential energy quandary.

The proposed solution focuses on educating the JMU community about the most potentially cataclysmic problem in human history - the energy crisis. Students across campus will be taught about the global, national, and especially residential energy use in order for learners to understand the severity of the situation today and the necessary efficiency, technology, and conservation changes needed to sustain today's standards for future generations. The amount of energy consumed in the residential sector in the United States is the most alterable through education. Therefore, informing students of these aspects encourage students to evaluate their current consumption habits and provide the necessary tools to enable them to alter their energy consumption behavior.

Recommendations for Further Work

It was stated in the 2012 RFP that there would be three student lecturers ready for Fall '12 semester. However due to one of the lecturers accepting a full-time position, the two remaining lecturers have decided that it would be more beneficial to postpone the course until the Spring 2013 semester. This will allow the course to possibly add another lecturer to the group along with providing more time for the current lecturers to become more comfortable with their styles of instruction. Now, we have 5 students-instructors that are practicing and fine-tuning the already made lectures.
Further work could include in depth studies of local homeowner's energy consumption. For example, electricity-monitoring instruments could be installed in voluntary participate houses in order to collect and analyze data. This could perhaps be an agreement between a Harrisonburg resident and JMU (ISAT department) to be responsible for monitoring the resident's home, granted the homeowner pays the upfront costs associated with the electricity-monitoring instrument. This would allow students access to a multitude of real home energy data and it would also facilitate an increase of energy efficiency and conservation in these local homes. Once this course has been implemented and evaluated, the PI is

contemplating the idea of offering this course to K-12 teachers for possible inclusion in K-12 curriculum.

Conclusions

In supplement of the JMU commitment to environmental stewardship, *The Energy Challenge* was created as a course to raise awareness on the energy debate. As part of the general education program, this course expands its outreach beyond students in the scientific field and is accessible to all majors. The conceptual significance of GSCI 101 is to promote a new outlook on the energy debate by introducing the details of daily energy consumption.

The composition of student researchers/instructors with various academic concentrations and the prevalent passion to address the energy crisis complimented the production of comprehensible material. As research and development finalizes, the remainder of this year will be devoted to solidifying lecture skills for implementation in the spring semester of 2013.