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Cyril B. Okhio
Clark Atlanta University

Florian Misoc

Austin B. Asgil

Aarick Aroz Zaman

Jarred Lee Prince

See next page for additional authors

Authors
Cyril B. Okhio, Florian Misoc, Austin B. Asgil, Aarick Aroz Zaman, Jarred Lee Prince, Olajimi Mark, Brion Allen Daffinson, and Olugbemiga Olatidoye

Sustainable Production of Ethanol from Kudzu: Experimental Prototype Studies

Dr. Cyril B Okhio, Kennesaw State University

Cyril Okhio, Ph.D., C.Eng.(PE), M.I.Mech.E., MASME, MASEE

SUMMARY Cyril B. Okhio is currently an Adjunct Professor in the School of Arts & Sciences, Clark Atlanta University. Dr. Okhio earned his B.S. (General Engineering) and Ph.D. (Mechanical Engineering) degrees from the University of London. He is registered as a Chartered Professional Engineer with the Council of Registered Engineers, United Kingdom; a Member of the Institution of Mechanical Engineers, UK and a Member of the Institute of Transportation Engineers, USA. Dr. Okhio has many years of administrative experience including the Chairmanship of the Mechanical Engineering Department, Bendel State University. Dr. Okhio has carried out experimental and numerical investigations of, and developed statistical analysis tools and computer codes, for the calculation of complex flows. Some of this work has been published in international journals. He is currently involved in multi-disciplinary research and development concerning Vehicle to Vehicle, Human to Vehicle Interaction and communication, under the purview of a Transportation, Vehicular Systems and Safety Engineering hub associated with SPSU Visualization & Simulation Research Center for which he is a co-PI. Dr. Okhio is very familiar with the level of technology and development, world-wide. He has visited many countries including Taiwan, Japan, Saudi Arabia, Zambia, Zimbabwe, Ghana, Senegal, Belgium, Germany, Austria, Italy, France, and he lived in the United Kingdom for more than 12 years. He is married with two children.

EDUCATION Ph.D. Mechanical Engineering Queen Mary College & Imperial College University of London, United Kingdom, April 1982 Dissertation Topic: Computational & Experimental Investigation of Flows through Wide Angle Conical Diffusers-applications in Combustion, Swirling Turbulent Flows, Multi-Phase, and Multi-Physics Flows. Thesis Supervisors: Profs. G. Langer; P. Bradshaw; H. Horton; B. Spalding. B.Sc. Engineering with Honors Thames Polytechnic-Woolwich College University of London, United Kingdom, July 1977 Dissertation Topic: Design, Construction & Testing of a Cross-flow Wind Turbine. Supervisor: Profs. Bittle & Jefferies. ACADEMIC HONORS & AWARDS • Shell BP, Outstanding Scholarship Award, 1972 -1974 • Shell International Oil Company Outstanding Scholarship Award, 1974-1980 • British Science & Engineering Research Council (SERC) Award, 1980-1983 RESEARCH FELLOWSHIPS • NSF-PSLSAMP Research Professor 2011 to 2012. Task -Design, Fabrication and Testing of 3 & 5 Bladed Ultra-Low Speed Wind Turbines for Modular Applications. • NSF-PSLSAMP Research Professor 2010 to 2011. Task -Design, Fabrication and Testing of 2 & 3 Bladed Ultra-Low Speed Wind Turbines for Modular Applications • Post-Doctoral Fellowship sponsored by Science & Engineering Research Council, England 1980-1983. Designed, Analyzed and Simulated A 2-D Separation Bubble in a Subsonic Wind Tunnel. • Summer Research PI, at NASA-Glenn Research Lab, Cleveland, OH, 1991- 1996. Designed Student Recruitment, Nurturing, Retention, Graduation & Tracking for Cleveland, Ohio community schools for Central State University benefit. Modeled flow transport processes in conical diffusers and turbine nozzles. PROFESSIONAL EXPERIENCE (Summaries) January 2013 – Present Adjunct & Research Professor (Articulation- GTRI) School of Arts & Sciences Dual Degree Engineering Program Clark Atlanta University Atlanta, Georgia August 2008 – 2013 Associate Professor of Mechatronics Engineering School of Engineering Southern Polytechnic State University Marietta, GA January 2010 - January 2011 Program Director/Founding Chair of Mechanical Engineering Department School of Engineering Southern Polytechnic State University Marietta, Georgia August 1996-August 2008 Associate Professor (Tenured) School of Arts & Sciences Dual Degree Engineering Program & Department of Engineering Clark Atlanta University Atlanta, Georgia October 1992-August1996 Director, CSU-NASA Resch Lab for Engineering & Technology - ReLEnT Department of Manufacturing Engineering Central State University Wilberforce, Ohio January 1988-Agust 2008 Associate Professor (Tenured) Department of Manufacturing Engineering Central State University Wilberforce, Ohio January 1988-August 1990 Associate Professor International Center for Water Resources Management Central State University Wilberforce, Ohio October 1993-August 1996 Associate Director Developing Nations Product Development Center Central State University Wilberforce, Ohio August 1984-January 1988 Chair

Department of Mechanical Engineering Technology Bendel State University Bendel State Nigeria. August 1981-August 1984 Post-Doctoral Research Fellow (Science & Engineering Research Council Award) Mechanical & Aeronautical Departments Queen Mary College, Imperial College University of London, United Kingdom.

INDUSTRIAL EXPERIENCE (Summaries) August 1974- 1983 Co-ops & Internships & Employment Shell-BP International Oil Company Waterloo, London, United Kingdom. August 1997- date Consultant (Distance Learning Strategic Planning) Peninsula Technikon Cape Town South Africa. October 1990-2003 Research Scientist (Low NOx Jet Engine Designs) General Electric/CSU Ohio. October 2002-2008 Research Scientist (Automated Inspection Systems) Ford Glass Company/CAU/GIT Memphis Tennessee. NOTED PROFESSIONAL SERVICES & AFFILIATIONS • ASEE: Reviewer for the 2015 International Conference Papers • Cyberjournals – Associate Editor • C.O.R.E.N. : Member, Council of Registered Engineers of Nigeria • M. I. Mech. E.: Corporate Member, Institution of Mechanical Engineers, UK • Member – Institution of Transportation Engineers, USA • Vice President, National Society of Professional Engineers, Cobb Chapter • Member, Board of Trustees, NSPE, Cobb Chapter • C.Eng. - Chartered Professional Engineer, IMechE, UK & Europe (#340366) • Member, American Society of Mechanical Engineers, ASME (#100714681) • Member, American Society of Engineering Educators, ASEE • Member, Advisory Board, Atlanta Technical College, Industrial Technology GRANTS, CONTRACTS & FELLOWSHIPS (Summaries) Total Grants & Contracts Participation Exceed $10 million Grant I: (PI - Cyril Okhio) Period: 1993-1996 Amount: $600K Agency: NASA Lewis Research Center Title: To carry out research under a unit titled "Research Laboratory for Engineering and Technology" (ReLEnT) at Central State University. Grant II - (Proprietary: PI - Cyril Okhio) Title: "Research Facility To Study Flows Through Annular Diffusers" Agency: GE/NASA-LRC Amount: $ 469K Period: 1994 - 1998 Grant III: (PI - Cyril Okhio) Title: NPARC - CFD Code Validation Experimentation for Component Designs. Agency: NASA Glenn Amount: $ 360K Period: 1996 - 1999 Grant IV: (Co-PI – Cyril Okhio) Title: Tertiary Education Linkage Program TELP Team: Collaborative - MIT, CAU, HU & NCA&T. Agency: USAID Amount: $2.5Million Period: 1996 – 2005 Contract V: (Collaborative with GIT) Co-PI - Cyril Okhio Title: Mechatronic Design of Automated IR-Based Inspection System Amount : $300K Period: January 1998 – October 2005 Agency: FORD GLASS and DoE Grant VI: (co-PI – Cyril Okhio) Title: Visualization and Simulation Instrumentation and Research Grant Amount: $200K (including SPSU Matching) Period: January 2009 – January 2011 Agency: Army Research Office DURIP Grant VII: (Collaborative with KIA) - PI Title: KIA-RULE KIA Research, Undergraduate Learning Experience Submitted: June, 2012 and funded Agency: KIA Motors, WestPoint, Georgia Grant Contract VIII: (PI) Southern Polytechnic State University Title: A Multi-disciplinary Study of Highway Safety Needs Analysis for Bicyclist and Pedestrians in Georgia. Submitted: July, 2012 Amount: $175K Not Funded Agency: Georgia Department of Transportation, R&D Division Relevance to Mechatronics: Transportation, Vehicular & Safety Systems, Diagnostics & Prognostics Research. Grant Contract IX: (PI) Southern Polytechnic State University Title: Advanced Vehicular Systems Research Award: 2 KIA Cars every 12 – 24 months for Research & Development. Procured: March 2014 Amount: $100K per year Agency: KIA Motor Manufacturing & Assembly Plant, WestPoint, Georgia Grant Contract X: (PI) Clark Atlanta University Title: Laboratory for Advanced Vehicular Systems Research & Training Award: 2 KIA Cars every 12 – 24 months Procured: Pending Amount: $93K per year Agency: KIA Motor Manufacturing & Assembly Plant, WestPoint, Georgia Grant Contract XI: (co-PI) Clark Atlanta University Title: Advanced Manufacturing Research & Development-MSIPP Consortium (CAU, NCA&T, HowardU, UDC, HamptonU, SUNO) Period: October 2012 to 2017 Amount: $6.5 mil funded Agency: DoE NOTABLE RESEARCH & EDUCATION ACTIVITIES (Summaries): • Research Studies on Advancing Student Participation in Campus Sustainability • Workshop on Eco-District Exchange • Establishing Research Paradigms for Sustainability, Safety & Recyclability of ALM Materials • Infusing Sustainability concepts into Science & Engineering Curricula • Development of Non-Destructive Flaw Detection Testing Laboratory for ALM Components (DoE-NNSA) • Development of Bio-Mechatronics Research Laboratory • Organizing to establish CAU as a USGBC-LEED Lab in the S.E. region • Design and development of a multi-disciplinary Eco-Entrepreneurship Program Curriculum SELECTED DESIGN PROJECTS 1. Experimental Investigation of the Mechanical Properties of Bone. 2. Design and Development of Bio-Compatibility Index for

Bio-Materials. 3. Experimental Ultra-low Speed Wind Energy Investigation for Modular Applications. 4. Studies on Sustainability, Recyclability & Safety of AM Materials. 5. Advancements in the study of the Impacts of student participation in Campus Sustainability. 6. Development & Implementation of Campus Sustainability Best Practices – CAU 7. Design, Development & Implementation of LEED Laboratories - a multidisciplinary immersion course that utilizes the built environment to educate and prepare students to become green building leaders and sustainability-focused citizens. 8. Design & Testing of Nozzles & Diffusers-Applications in AM Metal Powder Fed Systems. 9. Design of Experiments for NDT for AM Metal Components. 10. Design of Experiments for Surface Finish Evaluation of 3D AM Metal Components. SELECTED CONFERENCE SEMINARS & PRESENTATIONS • Okhio, C. B., Allen, R. G. (late), &. Indelicato, R. What Students Should know and How Teachers Can Guide the Development of Professional Engineers, Presented at the 8th Annual Interdisciplinary Conference for Teachers of Undergraduates: Teaching

Matters: Just What Do you teach?" March 2010. • Okhio, C. B., Masamoto, &. Stone, D. The Impact of 3D Development on Teaching & Learning: What Works – A Review. Presented at the 9th Annual Interdisciplinary Conference for Teachers of Undergraduates: Teaching Matters: Just What Do you teach?" Gordon College, March 2011. • How Teachers Can Guide the Development of Professional Engineers, Proceedings of the 8th Annual Interdisciplinary Conference for Teachers of Undergraduates: Teaching Matters: Just What Do you teach?" March 26 – 27, 2010. • Okhio, C. B., Hodges, D., Black, J. Review of Literature on Nano fluid Flow and Heat Transfer Properties, Cyber Journals: International Multidisciplinary Journals in Science and Technology, Journals of Selected Areas in • Nanotechnology (JSAN), December 2010. • Okhio, C. B., Waning, J., Mekonnen, T. M. An Experimental Investigation of the Mechanical Properties of Bamboo and Cain, Cyber Journals: International Multidisciplinary Journals in Science and Technology, Journals of Selected Areas in Bioengineering (JSAB), December 2010. • Okhio, C. B., Waning, J., Mekonnen, T. M. An Experimental Investigation of the Effects of Moisture Content on the Mechanical Properties of Bamboo and Cain, Cyber Journals: International Multidisciplinary Journals in Science and Technology, Journals of Selected Areas Bioengineering, (JSAB), November 2011. • Okhio, C. B., Masamoto, &. Stone, D. The Impact of 3D Development on Teaching & Learning: What Works – A Review. Proceedings of the 9th Annual Interdisciplinary Conference for Teachers of Undergraduates: Teaching Matters: Just What Do you teach?" Gordon College, March 2011. • Okhio, C. B., Adams, Mar Tia. Quantitative and Qualitative Analysis of Green Tea, White Tea and Hibiscus Extract and Their Performance as Corrosion Inhibitors. Cyber Journals: Multidisciplinary Journals in Science and Technology, Journals of Selected Areas in Bioengineering (JSAB), March 2012. • Okhio, C. B., Panaitescu, R., Asgill, A., Misoc, F., Tippens, S., Orekan, T. Energy Production and Consumption – Next 25 Years and Counting, Conference Proceedings, International Conference on Renewable Energy and Power Quality (ICREPQ'12), Spain, Vol. 13, March 2012. • Okhio, C. B., Asgill, A., Misoc, F., Orekan, T. Renewable Energy Resources – A • Case for the Tropics, Accepted for Presentation at the, International Conference on Renewable Energy and Power Quality (ICREPQ'12), Spain, March 2013. • Misoc, F., Ball, T., Asgill, A., Misoc, Okhio, C. B., Project-based Curriculum for Renewable Energy Engineering/Technology, ASEE Annual Conference Proceedings, June 25, 2013, page 118. • Okhio, C. B., Olatidoye, O., Misoc, F., Asgill, A. Incorporating Research into the Undergraduate Curriculum in Engineering and Engineering Technology-(E/ET) Lessons Learned. Abstract accepted for publication, ASEE Annual Conference, June 25, 2014

Dr. Florian Misoc, Southern Polytechnic College of Engr and Engr Tech

Dr. Florian Misoc is an Associate Professor in the Southern Polytechnic College of Engineering at Kennesaw State University. Dr. Misoc earned his Ph.D. in Electrical Engineering from Kansas State University. He also holds a Master's of Science Degree in Engineering Technology from Pittsburg State University, and a Bachelor's Degree in Physics from the University of Bucharest, Romania. He is a registered Professional Engineer in the state of Arkansas. Dr. Misoc's research is in the areas of renewable energy (generation, transmission and distribution), power electronics, and vehicular systems.

Dr. Austin B. Asgill, Kennesaw State University

Dr Austin B. Asgill received his B.Eng.(hons) (E.E.) degree from Fourah Bay College, University of Sierra Leone, his M.Sc. (E.E.) degree from the University of Aston in Birmingham, and his Ph.D. in Electrical Engineering from the University of South Florida. He is currently a Professor and Department Chair of Electrical and Computer Engineering Technology at Kennesaw State University (KSU). Prior to joining the faculty at KSU (formerly SPSU), he was an Associate Professor of Electronic Engineering Technology at Florida A&M University (FAMU), where he served as Program Area Coordinator and Interim Division Director. With over 25 years of teaching experience in Electrical/Electronic Engineering and Engineering Technology, he currently teaches in the areas of networking, communication systems, biomedical instrumentation, digital signal processing, and analog and digital electronics. He has worked in industry in the areas of telephony, networking, switching and transmission systems, and RF and MMIC circuits and system design. Dr. Asgill also has an MBA in Entrepreneurial Management from Florida State University. He has served on the board of the Tau Alpha Pi (TAP) National ET Honors Society since 2012 (Chair 2012-2014). He is a Senior Member of the IEEE, a Member of the ASEE, and is a licensed Professional Engineer (P.E.) in the state of Florida.

Mr. Aarick Aroz Zaman
Jarred Lee Prince
Mr. Olajimi Mark
Mr. Brion Allen Daffinson, Southern Polytechnic State University

Brion Daffinson is a Field Engineer at Amendia in Marietta, GA. Since graduating from Southern Polytechnic State University in May of 2015, he has taken his knowledge of mechanical design to the spinal device industry. Brion supports orthopedic surgeons and neurosurgeons with clinical issues, investigates medical device improvements, designs surgical instrumentation, and assists training and education of spine implants and procedures. He is a Certified SolidWorks Associate and is greatly interested in spine implant and instrument design. He finds it extraordinarily gratifying to develop a device to improve upon patients' lives and allow them to walk pain free. He hopes to gain experience in this field and hopefully play a part in the successful evolution of spine surgery procedures.

Dr. Olugbemiga Olatidoye, Clark Atlanta University

Dr. Olugbemiga A. Olatidoye is a tenured full Professor of Engineering at Clark Atlanta University (CAU). He is the Director and founder of the Visualization, Simulation and Design Laboratory (ViSiDeL) (A Virtual Reality Lab), and the newly created Center for Alternative, Renewable Energy, Technology and Training (CARET2) / AUC Sustainable Campus Community Initiative (ASCCI) / Center for Additive Manufacturing. He is the Coordinator of Dual Degree Engineering program at CAU, (http://www.cau.edu/Academics_DDEP_Welc He also directs the Electronic Commerce Resource Center (ECRC) at CAU. Among other Centers he directed at CAU are Army High Performance Computing Center (AHPCRC) and DoD Major Shared Resource Center (Army Research Laboratory (ARL), Army Corp of Engineer Waterways Experiment Station (CEWES) and Aeronautic System Center (ASC) Wright Patterson Air Force Base), all of which are Department of Defense (DoD) funded projects (http://www.visidel.cau.edu) (http://www.caret2.com).

Dr. Olatidoye received his Bachelor degree in Architectural Engineering in areas of Structures from North Carolina A&T State University in 1982. He completed his Masters degree in Architecture (Solar Energy), at Virginia Polytechnic Institute and State University (Virginia Tech), another Master degree in Civil Engineering, in Engineering Computer Graphics at Georgia Institute of Technology and State University (Georgia Tech), Atlanta. Other degrees from Georgia Tech are Knowledge Engineering and Doctorate degree with emphasis on Intelligent Graphics. He was a member of the Board of Directors at Georgia Tech. He is also a member of the Board of Director for the Georgia Youth Apprenticeship program of the Atlanta Public Schools. He is a Structural Engineer by practice. His research areas include "The Design and Application of an Optimization Model for Thermal Performance of Atrium Buildings", his thesis at Virginia Polytechnic Institute and State University, Blacksburg, Virginia in 1985, leads to the "Development of a User Friendly Micro Computer Analysis Method For Assessing Energy Retrofit Options In Residential and Light Commercial Building". Other areas of research are on Biofuel production, Structural Dynamic, Visualization, Simulation and Design. He is presently the faculty advisor for the Students Chapter of the National Society of Black Engineers at the Atlanta University Center (AUC). He had chaired and presented at several notable conferences such as World Automation Congress Conference. Recently he was selected to serve on the proposal review panels for National Science Foundation (NSF) Interactive Graduate Education and Research Training (IGERT) program as a Lead reviewer, Writer, Reader and Scribe. Prof. Olatidoye has written over 90 proprietary technical papers that span over four Universities and Industries. He has also several publications in refereed journals and conference proceedings and Chair several Conference sessions and as invited speaker on several occasions. He started a consulting firm 1985, Tido Tech International (TTi), http://www.ttics.com. He is a member of the "Men of Valor" at the East West Church in Marietta, Georgia. He is also a member of the US Army Science Board.

C. B. Okhio Ph.D., C.Eng.*, F. Misoc PhD., PE.*, A. Zaman*, J. Price*, J. Mark*, B. Daffinson*, D. Sharpe*, O. Olatidoye
*Kennesaw State University
(Southern Polytechnic School of Engineering & Engineering Technology)
1000 S. Marietta Parkway
Marietta, GA 30060
cokhio@kennesaw.edu

Abstract
Experiments show that Georgia Kudu contains about a 50/1 carbon/nitrogen ratio. The generally accepted and in-use carbon to nitrogen ratio is around 30/1 and this can usually be achieved through well understood fermentation and distillation technologies as described here. These processes are the techniques through which Ethanol is extracted form sugar cane and corn. This research effort shows that Kudzu Plant (a wild growing weed/plant in the state of Georgia and elsewhere) can be a viable, however not a standalone source of ethanol. The initial focus of this effort was on the plant itself, and the current associated products and uses. As the literature revealed, Kudzu is a viable source of Ethanol. Thus, with this renewable source of Ethanol, it is conceivable that a good alternative source for the enhancement of Bio-Fuels production from Algae and other Vegetable Oils has been found. The later effort then provided the needed basis for the answers to the "how" aspects of the production technology. The initial design approach in this effort, were limited to three aspects: harvesting, processing and product distribution. The final designs show strong promise for Ethanol production from Kudzu. These will include ergonomic harvesting, processing the material from actual plant matter all the way to distillation into Ethanol, and conceptual designs for harvesting from places where Kudzu has become a nuisance in combination with harvesting from Kudzu farms yet to be established.

Key Words:
Sustainable, Energy source, Ethanol, Kudzu Plant, Vines, Tap-Roots, Fermentation, distillation, Sugar Cane, Algae, Vegetable Oils, Corn, Carbon-to-Nitrogen Ratio, Ergonomic harvesting, Processing, Design of experiment

Introduction

America consumes about twenty-five percent (25%) of the oil produced around the world, but our nation holds less than three percent (3%) of the world's proven oil reserves (Energy Information Administration). The Department of Energy estimates that by the year 2025, our dependence on oil would increase by nearly 70 percent (Durante). With these two strong facts, the United States simply cannot continue to rely on oil as we have in the past. The Energy Tax Act of 1978 was the first response to the petroleum crisis. That response increased the demand for alternative and renewable fuel sources: "Our overall gasohol program will spur the investments that we, together, must make for a more secure energy future. We will create new markets for our farmers. We will no longer have to throw away waste materials which can be turned into profitable essential fuels" (Carter, 1980). The United States foresaw that an alternative fuel source would be viable and needed.

Congress, innovators and entrepreneurs in the United States, have come together to create new technologies and alternative fuels to lower the nation's dependence on foreign oil and petroleum. They asked themselves: What can be used as an alternative fuel source that can replace energy sources such as gasoline? The review of literature and research revealed that Bioethanol is the clue. Bioethanol is an alcohol-based fuel made from plant materials. One plant that was determined to be a viable source of ethanol was corn. Consequently, farmers across the nation have increased corn production to meet the growing demand for corn-based ethanol.

Seeing that corn would eventually not be a sustainable source of bioethanol due to the fact that it is a primary food source in the United States and elsewhere, this study was initiated to find an alternative to corn, called “Kudzu Plant”. Initially, this research project was intended to design, build, and test a model Kudzu-Oil production plant. Then it was extended to determine whether Kudzu can be used as a sustainable source for ethanol.

Why Kudzu? This is an interesting question - why use the plant Kudzu as a production source for ethanol? It is a question that hasn’t crossed many people’s minds, but for those who it has, the answers are quite promising. The demand for ethanol in the United States is rising rapidly. In 2005, 13.6 percent of corn produced went towards the production of ethanol, and with the high demand, it continues to rise each year (Cooper). Should we not further explore an invasive and abundantly available weed such as Kudzu for its value as a source of ethanol fuel rather than a food source?

There are numerous advantages to using Kudzu as a raw material for the production of ethanol rather than other methods such as corn. Kudzu grows one foot a day, sixty feet a season, and can be harvested twice a year. All parts of the plant (root, vines, and leaves) are productive, so no leftovers are wasted after harvesting. Kudzu has a very large weight of carbohydrates; it constitutes at least 2/3 of the plant weight. Also it is cheap, and the price will not be raised because it is not tied to the commodities market (BioZio). One big advantage of using Kudzu would be replacing corn. Corn is an incredibly important crop. Corn is used to feed livestock, and in production of nearly every food or beverage product. With its high demand, the price of corn is rising as well. American corn supplies are dropping due to drought and its use for ethanol. This leads to many problems such as widespread inflation, world hunger, less food security, slow economic growth, and political instability (Carter). Using Kudzu solves two problems: the problems resulting from using corn as a production of ethanol fuel, and the removal of the invasive weed from destroyed and overtaken crop fields. Sugar cane is another common source of ethanol production, but it is another food source that is in high demand.

The amount of ethanol that can be processed from Kudzu is comparable to that of corn. Corn can produce about 2.8 gallons of ethanol per bushel (Cooper). Experiments in the literature (BioZio) shows that five gallons of Kudzu mash, equals about half a gallon of ethanol, which can produce about 270 gallons of ethanol per acre. This is comparable to corn which amounts to anywhere from 210 to 320 gallons per acre (BioZio). Also, Chem-Tech Research shows that Kudzu plants containing the optimum Carbon/Nitrogen ratio of 35.2 produces an ethanol yield of 8.85 grams/liter (Manikandan). Samples returned a C/N ratio close to 50, being well suited for ethanol production. Our sample was the vines of the Kudzu plant, picked in Marietta, Georgia and Cohutta, Georgia. Again the advantage with using Kudzu is that every part of the plant can be utilized, with the vines actually producing the least amount of sugars and starches, leaves producing slightly more, and the most productive being the roots (Sage).

The advantages that Kudzu provides as a means of ethanol fuel cannot be under-estimated because it can help replace other sources of ethanol production. Besides, the plant is a burden to many. Our sources help unveil the potential for using Kudzu to produce ethanol fuel, as do our lab samples.

Processing: Harvesting

Initially, the vines and leaves of the kudzu plant were expected to be the primary raw material for ethanol production. The focus on green material led to preliminary designs of the harvesting process (Figure 1), which focused on maximizing the amount of growth per square foot. The design focused on suspension of hollow spheres containing soil and a seedling of kudzu across a strand. Strands were suspended in vertical rows. However, further investigation determined that the most desirable portion of the plant was actually the ‘taproot’.

Once the taproot became the target of the harvest, further design of experimentation were explored. Hollow cylinders with holes at equally spaced intervals will become the nesting beds for the kudzu seedlings with cylinders being vertically set in the ground, filled with soil (Figure 2). Since kudzu flourishes in any kind of soil, locally gathered substrate can be used. This means that the added cost of potting soil will not impact the production cost. Using the cylinders also makes the process of harvesting the taproot of the plant a more controllable process.

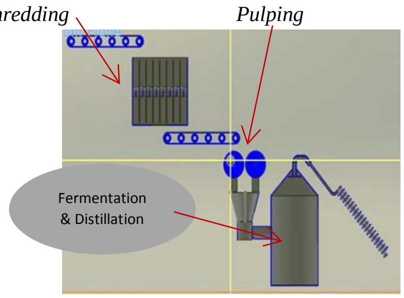


Figure 1: Processing Steps

Figure 2: Harvesting Solutions

The harvesting process begins in January with setting up the cylinders and filling them with soil. Once the cylinders are erected and filled, seedlings will be planted in each of the holes in the cylinder surface. As the plants grow, the leaves and vines will be harvested on a weekly basis. Since the cylinders will be uniform in shape, the development of a semi-automated harvesting device would be feasible. The plant matter will be harvested until the plant goes dormant in late fall. By December the taproot will have built up the stores of sugar that allows for the plants explosive growth during the spring. At this point the cylinders will be removed and emptied into a tumbler device that will shake the soil. This process will separate the roots from the soil. A similar device is used in the harvesting of potatoes. This will be the primary source of material for the ethanol production process. A secondary source can be found in the other parts of existing kudzu plants.

Secondary Harvesting

Secondary harvesting will occur during the winter months when the kudzu is dormant. Since kudzu is a feral plant, a case could be made that eliminating grouped infestations of the plant would yield environmental benefits. This argument could be levied to obtain federal or private grants to subsidize the harvesting of wild kudzu. Local and state governments will be offered the opportunity to have their lands infested with kudzu to be cleared. The governments would pay for the cost of removal and transport of the kudzu. Since the process removes the taproot that makes kudzu so resilient, the infestation could be eradicated, which eliminates the government's annual expenditure to control the kudzu, and yields the chance to use the land for purposes that may generate tax revenue. The time of the year would reduce the risk of wild encounters such as snakes. The process sounds simple, but obstacles still exist to tapping into this existing reserve of source material.

One major obstacle will be the randomness of the terrain encountered. Many areas infested with kudzu are completely covered, which masks the terrain beneath the plant. This unpredictable nature could prove hazardous to harvesting machinery and workers. A method of prevention would be having the terrain of each possible zone mapped before making any attempt to harvest. These mapping reports could be used to form a grading scale that quantifies the viability of each plot. The reports would list ground conditions as well as identify any large obstacles hidden by the kudzu (i.e. derelict cars, washing machines). Fees and subsidies could sanction the existing kudzu to become a source material during the winter in which the production process has slowed due to lack of available material.

Production Process

Production will begin by breaking down the plant matter into a "mash" (Figure 3). The plant matter will be fed into a large scale shredding machine that will chop the kudzu into a pulpy consistency. Initial designs for the shredder involve metal box containing interlocking blades spinning on two parallel rods. The blade axles are also parallel to the ground. Three pairs of blades will be stacked vertically with each pair of blades being closer together as the material descends. The actual spacing and speed of the blades will need to be determined through testing. The pulp exiting the shredder will move on to the next stage by a trough containing a conveyor system (Figure 1).

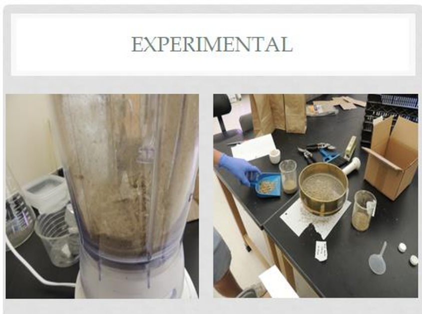


Figure 3: KUDZU Blending & Mashing

Figure 4: KUDZU Sampling

A secondary breakdown stage will take place as the mash is fed into mashing device. Steel drums mounted parallel to each other with an exterior force pushing the cylinders together. The drums spin towards each other, which will feed the source matter in between the drums resulting in mashing and further breaking down the material. As the material exits the masher, it will be fed into storage tanks. The storage tanks are where the actual fermentation will take place. An ideal size for the tanks will need to be determined by testing. Once the source matter is in the tank, it will be combined with appropriate amounts of yeast and water. The tanks will be sealed and moved to a storage area for fermentation to take place. Fermentation time is another variable that will need to be determined by experiment. An estimate is of the order of 2-3 weeks, but will vary based on any number of environmental factors. Once fermentation is complete the mash will be ready for distillation.

One design alternative is that the storage containers will also serve as the distillation tank. Connections used to extract the ethanol would be capped during the fermentation process. One connection will connect the tank to the condensing coil to collect the ethanol. A second connection will collect byproducts produced below the ideal temperature (i.e. methanol 148°F).The tank would be moved to the distilling area and placed over a heat source. The boiling point of ethanol is 173.1°F which is far below water's boiling point of 212°F. Collection will involve several steps including monitoring.

As the temperature in the mash rises it will reach plateau points. These points will signify when a component of the mash is being boiled off. As previously mentioned, the boiling point for methanol is 148°F. Once the methanol begins to boil off, the temperature will hold steady until it is all gone. The steam produced at this time is not the desired product, but could prove to be a commodity. Methanol could be sold to chemical companies to produce products such as formaldehyde, plastics and other Algae oil derivatives. So, as this temperature is reached, an automated valve would open, allowing for the collection of methanol into its own specific condensing coil that feeds into a designated collection tank. Once the temperature begins to climb again, the valve will close until the target temperature for ethanol is reached.

When the target temperature of 173°F is reached, the valve designated for ethanol will open and the steam will collect into the designated condensing coil. The condensing coil consists of copper pipe in a spring shape contained within an insulating chamber. This insulating chamber could be water cooled to accelerate the condensation of the steam back into liquid ethanol for collection. It is unknown whether it will be beneficial to continue the heating process so the water can be collected from the tanks and recycled. The idea is worth investigating, but will likely involve some cleaning and processing to be useable again. Since the goal of this endeavor is to find a more sustainable fuel source, minimizing the production of waste water should be a priority.

Waste Materials:
Once distillation is complete, the left over mash still exists. Possible options for disposal will depend on whether the end material contains any toxins. Mulch and fertilizer seem to be obvious choices for post-production use of material. A portion could be used to promote growth of seedlings for the following year's crop or to enrich the soil used for planting. Steps will be taken to recycle water used in the process. The harvesting cylinders will be reused until no longer viable, and a possible choice of materials could be recycled plastics. Being exposed to the sun would allow the plastic to breakdown in the sunlight so that they do not contribute to the landfill.

Facility Requirements:
The ethanol production facility will need a large portion of land to grow and harvest the kudzu. The plant must be grown onsite to reduce shipping costs to the factory. An onsite water source would also be desirable for onsite irrigation. Having water well on the property would also reduce costs involved with using municipally supplied water. The land will also have to be stable enough to allow for subterranean storage tanks. Ethanol and many by-products of the process are volatile. The storage tanks and distillation plant will need to be protected from collection of static charges, sparking and open flames.

Experimental Results
Results and Analysis: Lab Data: Cohutta & Marietta

Cohutta:
Fresh Kudzu
Bag weight: 10.1 g
Fresh Clippings + Bag = 62.25 g
Kudzu Weight: 52.15 g

Oven In: 10:54 am (04/05/2013) **Oven Out**: 10:01 am (04/08/2013) Temperature: 110 F

Dried Kudzu
Bag weight: 9.93 g
Bag + Kudzu = 48.33 g
Kudzu Weight: 38.40 g

Powder Yield
Beaker: 68.21 g
Beaker + Powder = 69.98
Powder Extract: 1.77 g
Excess Material: 1.46 g

Recorded Weight Sample Containers
C1: 6.01 g
C2: 6.41 g
[Note: C1 & C2 are total weight of packed material + capsule.]

Marietta:
Fresh Kudzu
Bag weight: 10.07 g

Fresh Clippings + Bag = 64.82 g
Kudzu Weight: 54.75 g

Oven In: 10:54 am (04/05/2013) Oven Out: 10:01 am (04/08/2013) Temperature: 110 F

Dried Kudzu
Bag weight: 9.96 g
Bag + Kudzu = 56.45 g
Kudzu Weight: 46.49 g
Powder Yield
Beaker: 68.71 g
Beaker + Powder = 70.68 g
Powder Extract: 1.97 g
Excess Material: 2.62 g

Recorded Weight Sample Containers
M1: 7.25 g
M2: 7.22 g
[Note: M1 & M2 are total weight of packed material + capsule.]

Notes:
- Marietta Powder has healthier, deeper earth tone brown color than the Cohutta
- Marietta Powder appears denser in characteristics too.

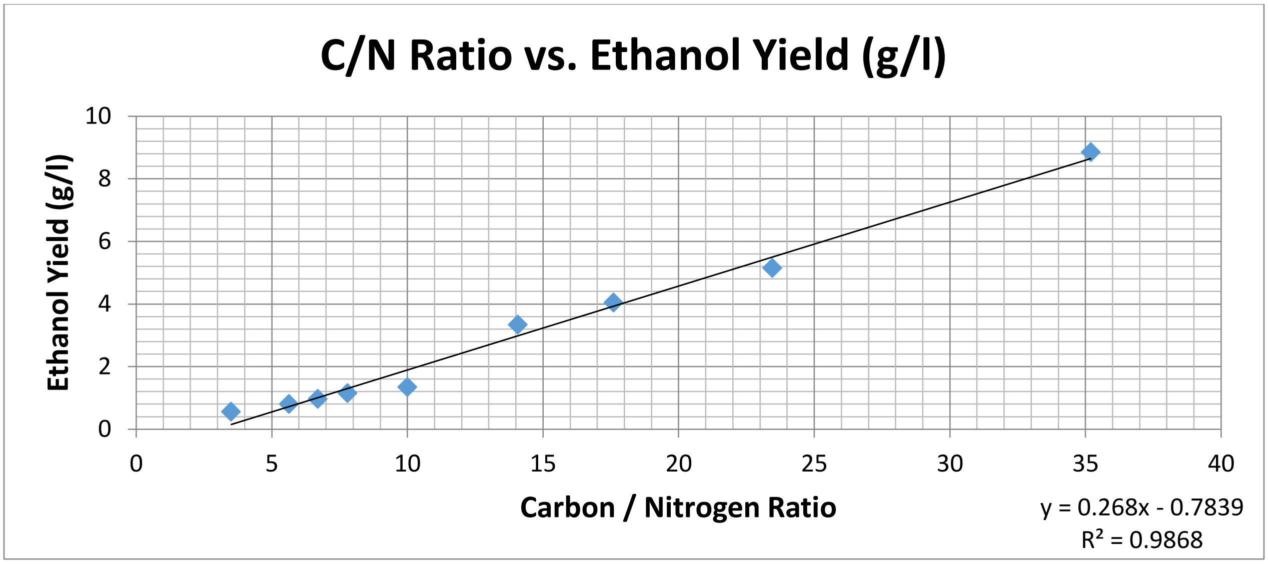
Sources of Error:
- Powder leach onto table, affecting percent yield obtained.

Daffinson, Brion
1100 S. Marietta Parkway SE
Marietta GA 30060
Plant Tissue Samples
Completed: April 11, 2013

From: Soil, Plant, and Water Laboratory
2400 College Station Road
Athens, GA 30602
phone: 706-542-5350
e-mail: soiltest@uga.edu
http://aesl.ces.uga.edu

		%							ppm										
Lab	**Sample**	**C**	**Ca**	**K**	**Mg**	**P**	**N**	**S**	**Al**	**B**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Mo**	**Na**	**Ni**	**Zn**
2167	C1	50.6	0.89	1.18	0.19	0.13	1.72	0.08	102.8	21.31	<0.40	<1.00	9.90	116.1	20.3	1.23	<2.00	2.65	70.5
2168	M1	49	1.97	0.74	0.27	0.05	1.63	0.08	253.6	32.78	<0.40	1.11	9.94	264.4	99.4	<1.00	15.03	<2.00	113.0

Plant Analysis Handbook for Georgia



Carbon / Nitrogen Ratio	Ethanol Yield (g/l)
3.5	0.55
5.63	0.8
6.7	0.96
7.8	1.15
10	1.34
14.08	3.34
17.6	2.02
23.46	5.14
35.2	8.85

Sample	C/N Ratio	Approx. Ethanol Yield
C1	29.44	7.106 (g/l)
M1	30.06	7.272 (g/l)

Sample	Percent Yield
Cohutta	3.39 %
Marietta	3.60 %

Lab Analysis & Deductions:
Two separate samples of kudzu vine from Cohutta, Georgia and Marietta, Georgia were tested. The results indicate approximately 3.45 % yield of viable powder from a volume of kudzu vine. Data acquired from experiments at the UGA laboratories show that both Georgia samples contained a carbon/nitrogen ratio of about 30, which is as expected. According to the created trend-line, this will result in 7.189 g/l of ethanol. With the low percent yield of powder, a very large quantity of kudzu would need to be harvested to create enough ethanol.

Conclusion
Designing, building and testing a model Kudzu- Oil Production plant was achieved. It was discovered that there were several advantages to using Kudzu in the production of ethanol. However, with current methods, more work need to be done to make it a viable replacement for present day other sources of supply. This research indicates that the taproot is the most desirable portion of the plant, shifting focus away from the leaves and vines alone. The entirety of our research and tests show that Kudzu is a viable source of ethanol, but will require further innovation to become a standalone source of ethanol so as to rival corn, or sugar cane. KUDZU will be adequate for a modest domestic production source for Ethanol. In addition, Kudzu-based ethanol will be better suited for the production of biofuel: that is, bio-diesel and

bio-gasoline, as opposed to corn-based ethanol for obvious reasons. Thus, the extensive development of Kudzu ethanol will substantially reduce the use of corn for biofuel production. Research also reveals that oil extraction from microalgae through hydrothermal liquefaction is the most efficient method of bio-oil production (M. Tantiphiphatthana et al 2015). Therefore, further investigations will be carried out to determine the cost effectiveness of microalgae-based bio-gasoline, blended with Kudzu-based Ethanol, as an enhancement of the octane index.

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Nomenclature

Kudzu:	Pueraria lobata – vine based feral plant (brought to US from Japan in 1876)
C-N:	carbon to nitrogen ratio
Ethanol:	ethyl alcohol (used in fuel)
Fermentation:	the conversion of sugar to acids, gases and/or alcohol using yeast or bacteria
Distillation:	a method of separating mixtures based on differences in volatility of components in a boiling liquid
Methanol:	methyl alcohol
Condense:	to take a product in and return one smaller
C1, M1:	Samples sent to UGA Plant and Soil lab. (C1 = Cohutta, M1 = Marietta)

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