AN ABSTRACT OF THE DISSERTATION OF

Kimi Grzyb for the degree of Doctor of Philosophy in Environmental Sciences presented on June 13, 2017.

Title: Bioenergy Education: A Curriculum Framework and Interdisciplinary Minor

Abstract approved: ______________________________________________________

Katharine G. Field

Bioenergy is a rapidly growing subsector of the emerging global bioeconomy, with the potential to create a substantial number of jobs and mitigate climate change. In order to develop bioenergy into a viable industry, capable of providing valuable energy and employment, there is an immediate need for a skilled workforce prepared for the impending challenges of this interdisciplinary field. However, programs providing training for these positions are limited, and there is currently a lack of research-based guidance for the creation of new educational programs. To meet this need, it is necessary

to identify and prioritize the topics that should be included in a college-level bioenergy curriculum and determine best practices for bioenergy education. In order to gain insight into expert and academia priorities and how they can be applied in an academic program, two Delphi studies, combined with a case study of an existing minor degree program at Oregon State University, were implemented.

During the first Delphi study, an iterative, mixed-methods approach used to reach group consensus, 12 bioenergy experts in both educational and employment sectors provided open-ended responses to the following question: Keeping in mind the future of a commercial bioenergy industry, what content knowledge should a student have upon completion of a college-level bioenergy curriculum? Responses were qualitatively coded into themes, and experts were asked to rate the importance of each theme using a five-point Likert-type scale during two subsequent rounds. The final round resulted in the following 13 themes, listed in order of importance: Energy Basics, Types of Bioenergy, Environmental Impacts (including Life Cycle Analysis), Current Technologies, Societal Issues, Logistics, Policy, Biomass Composition, Non-Bioenergy-Specific Fundamentals, Biomass Production, Conversions, Bioenergy Market, and Business-Related Knowledge.

The second, two-round, modified Delphi study asked 47 experts to use the same scale to rate these 13 themes, and they were welcome to suggest additional items, resulting in the addition of Bioproducts. Academia and industry responses were then compared, which revealed that their priorities were well aligned.

Alumni interviews and current student surveys were conducted to evaluate the bioenergy minor at OSU. Analysis of these responses provided input from the students' perspective.

Findings indicated that students value the required research experience and the interdisciplinary nature of the minor degree, among other qualities of the program.

Bioenergy is an interdisciplinary, complex, and evolving field. The Delphi studies distilled numerous technologies and associated topics into a college-level curriculum framework, while the case study examined an existing minor degree program and illustrated how the program has transformed based on student feedback. Results are intended to bolster emerging bioenergy training programs to meet the needs of future employers. The combination of methods provided a curriculum framework and example of an existing program, both of which may be adapted for region-specific technologies to support a forthcoming bio-based economy.

©Copyright by Kimi Grzyb

June 13, 2017

All Rights Reserved

Bioenergy Education: A Curriculum Framework and Interdisciplinary Minor

by
Kimi Grzyb

A DISSERTATION

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Presented June 13, 2017
Commencement June 2018

Doctor of Philosophy dissertation of Kimi Grzyb presented on June 13, 2017

APPROVED:

Major Professor, representing Environmental Sciences

Director of the Environmental Sciences Graduate Program

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Kimi Grzyb, Author

## ACKNOWLEDGEMENTS

The author expresses sincere appreciation first and foremost to my loving and supportive parents, Alan and Robie Grzyb, for everything they have done to make this possible – Love you! I would also like to express heartfelt gratitude to my dear Major Professor, Dr. Kate Field, for her exceptional mentorship and inspiration along this journey. I also wish to thank my other wonderful committee members: Dr. Hong Liu for her encouragement to pursue my passion for education, Dr. Lori Kayes for providing me with opportunities in biology and letting me dog sit, Dr. Darlene Russ-Eft for her guidance throughout the IRB process, and Dr. Ricardo Mata-Gonzalez for being an excellent grad rep. In addition, I would like to thank Dr. Brian Hartman for his assistance with the qualitative coding of my Delphi studies, and for being a motivational coworker and enjoyable conference travel companion. Additionally, I deeply thank all of my incredible friends and loved ones for providing me with many opportunities for fun, especially the outdoor adventures, which kept me sane throughout this process. Special thanks, also, to my adorable nephew, Rocco, for bringing me extraordinary joy during our visits. Finally, I would like to thank the OSU Bioenergy Education Initiative for being a great team, and Advanced Hardwood Biofuels NW and the USDA for funding this endeavor.


“Education doesn’t change the world. Education changes people.

People change the world.”

- Paulo Freire

# CONTRIBUTION OF AUTHORS

Dr. Brian D. Hartman assisted in coding of the qualitative data for Chapters 2 and 3.

Dr. Glen Li assisted with the description of the newly proposed minor modifications presented in Chapter 4.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

# CHAPTER 1

## Introduction and Literature Review

### Statement of the Problem

World energy consumption is predicted to increase by 56 percent between 2010 and 2040 (www.eia.gov). There is a strong need to find feasible solutions to meet this demand, which requires a workforce that is knowledgeable in alternative forms of energy production. Heavy reliance on fossil fuels for energy needs has resulted in accelerated climate change and dependence on foreign oil suppliers, which compromises global environmental health, national independence and energy security (e.g. Mathews, 1989). Bioenergy, or renewable energy produced from organic matter, has existed since the first humans began burning wood for heat and cooking purposes, but recently it has gained international attention as a potential solution to our planet's growing energy requirements (Demirbas, 2009). However, despite its promising role in contributing energy to impending needs, bioenergy is largely unfamiliar to the general population. In response to an open-ended question posed to 1,001 random American adults asking them to name sources of renewable energy, shockingly few listed ethanol (6%), wood (2%), "biofuels" (2%), biodiesel (1%), or waste products (1%) (Bittle, Rochkind, & Ott, 2009). Similarly, only 10% of Europeans were able to identify a biofuel used as a source of energy (Rohracher et al., 2004). Clearly, there is a need for improved education and societal focus in this arena.

Although there is a severe lack of public awareness, bioenergy serves as a large source of energy used globally (US DOE, 2011). Biomass constitutes 50% of U.S. renewable energy production (US Energy Administration, 2013), and in support of U.S. Congressional goals for biofuels, production targets of 36 billion gallons per year by 2022 have been set (e.g. Sissine, 2007). Much research is currently being conducted to improve the process of converting the solar energy stored in living and recently living organisms to a form that can be utilized efficiently and cost-effectively to the benefit of society and the environment (Warnmer, 2007). Improved technologies developed from this research are continually advancing the conversion of biomass to biofuels, which strongly suggests that the importance, applicability and utilization of bioenergy will continue to grow (Pasztor & Kristoferson, 1990).

Moreover, bioenergy plays a vital role in establishing a successful bio-based economy (bioeconomy). The bioeconomy is an emerging economy, driven by innovation and research in the biosciences, which has the potential to lead to healthier lives for Americans, lower healthcare costs, transformed manufacturing practices, and improved agricultural productivity to meet the needs of the growing population (White House, 2012). Figure 1.1 illustrates the critical roles that both bioenergy and human capital will play in a successful bioeconomy; education is depicted as one of the three main drivers of change (Smáradóttir, 2014). Furthermore, increased awareness of bioenergy and other renewable energy options may assist in promoting consumer use and preferences for these alternatives (Zografakis, Menegaki &Tsagarakis, 2008), which is mandatory for the industry to be successful. An important, additional benefit of a prosperous bioenergy industry is the numerous domestic employment opportunities it will create, especially in rural areas, and appropriate workers will be needed to fill these positions (Becker et al., 2009; Mathews, 2008).

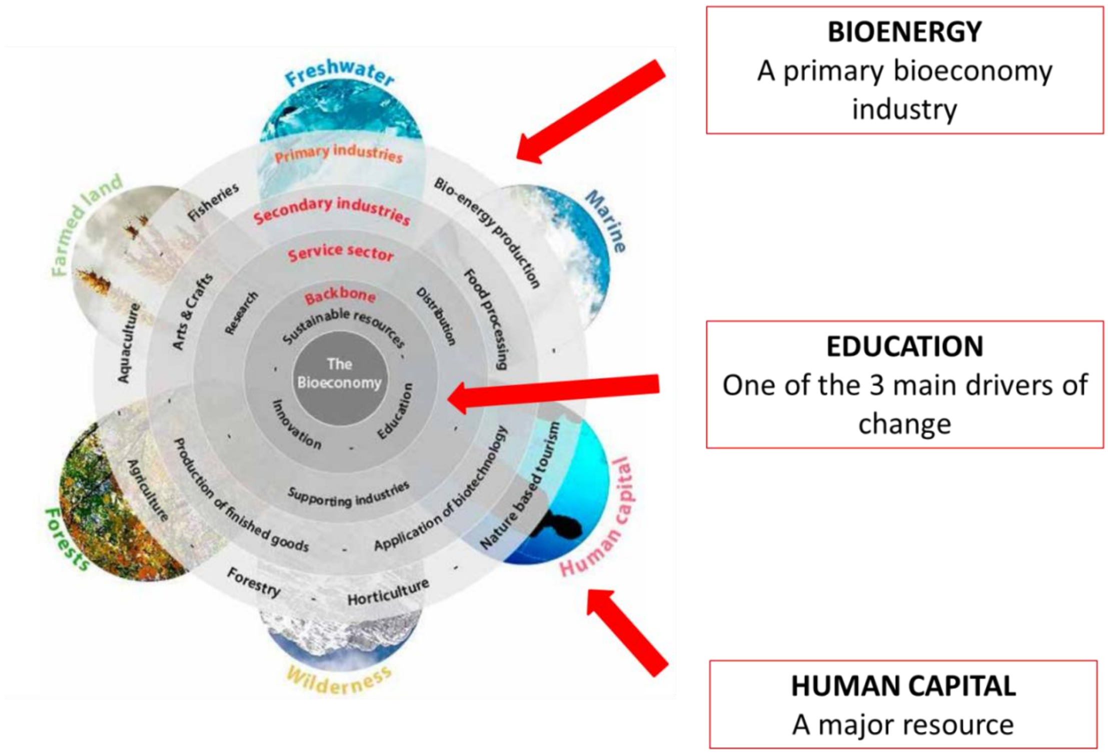


*Figure 1.1*. The bioeconomy and the importance of bioenergy, education, and human capital.
Source: Adapted from Smáradóttir et al. (2014).

As the bioenergy industry and job market continue to grow (White & Walsh, 2008), a well-trained workforce capable of implementing innovations and meeting impending challenges will be required. However, currently there is a severe deficiency in training programs and courses dedicated to bioenergy (Ransom & Maredia, 2012). Because "a vibrant bioeconomy depends on the education and skills of its workers" (White House, 2012, p.33), the National Bioeconomy Blueprint includes updating training programs as one of its five strategic objectives, specifically stating that institutions should be incentivized "to adapt training to meet the needs of the 21st-century bioeconomy workforce" (White House, 2012, p.5). However, due to the vast, interdisciplinary, and complex nature of the field of bioenergy, it can be difficult for educators to prioritize the topics that college students should be knowledgeable about in order to be desirable, productive employees. Determining and prioritizing pertinent components of a college-level bioenergy curriculum, utilizing the expertise of both educators and industry professionals by employing the Delphi method, provides a general educational framework for this growing field. Including experts from both academia and industry ensures a broad range of input and allows a comparison between the two groups to determine whether their priorities are aligned. In other words, are students being taught what potential future employers want them to know?

Complementing the Delphi research is a case study analysis of the interdisciplinary bioenergy minor offered at Oregon State University (OSU). This minor was created as part of the education component of the Advanced Hardwood Biofuels Northwest consortium (hardwoodbiofuels.org), funded by the United States Department of Agriculture (USDA). First offered in 2013, the minor now has 13 graduates, 30 current students, and approximately 100 students enrolled in the component courses created specifically for the minor. The minor degree requirements are described in detail, and interviews and surveys provide student feedback about the program. As a pioneering undergraduate bioenergy minor degree program in the US, this program can serve as a model design for emerging bioenergy degrees and/or other educational programs.

The combined Delphi and case study findings from this bioenergy education investigation can aid in reforming current bioenergy curricula and offer guidance for the creation and establishment of new training programs. Ultimately, results of this research can assist in providing students, who will become tomorrow's bioenergy innovators, the tools necessary to obtain critical job positions that will enable them to contribute to the progression of a national bioeconomy.

**Organization of the Studies**

This dissertation is organized into five chapters. Chapter One describes the need for this study, provides context, defines key terms, and reviews the literature on relevant elements of this research including: the Delphi method, existing bioenergy education programs, T-shaped employees, interdisciplinarity, experiential learning, and undergraduate research experiences. Chapter Two, Determining Essential Components of a College-Level Bioenergy Curriculum, presents the results of a pilot three-round Delphi study in the form of a college-level bioenergy curriculum framework. This is a stand-alone paper that has been submitted for publication to the journal Renewable Energy. Chapter Three, Comparing Industry and Academia Priorities in Bioenergy Education: A Delphi Study, utilized the results from the pilot study as a starting list for a modified two-round Delphi study. In this expanded study, a larger panel of experts prioritized curricular components, and priorities between educators and employers were compared. This stand-alone paper will be submitted to the International Journal of Sustainability in Higher Education. Chapter Four, An Interdisciplinary, Research-based Minor in Bioenergy, describes an existing program at OSU that encompasses many of the aspects deemed important in the Delphi studies, and also presents feedback from current students and graduates of the program. Chapter Four is also a stand-alone paper and was submitted to the Journal of Education for Sustainable Development. Finally, Chapter

Five, Discussion, includes recommendations for effective bioenergy education, conclusions, and implications of the study overall. All Delphi materials, including invitation letters, reminders, and instruments, as well as student surveys and interview questions, are included as appendices (See Appendices A-K).

## Review of the Literature

### *Need for Bioenergy Education and Existing Programs*

Industrial biotechnology, which includes bioenergy, is the fastest growing subsector of the national bioeconomy (Carlson, 2016), and this trend is expected to continue both domestically and abroad (Savolainen, Honkanen, & Vertainen, 2013). Moreover, more jobs will be created in bioenergy than other renewable energy options because it is more labor-intensive, and the cost per job created is lower than average petro-chemical employment investments (Domac, Richards, & Risovic, 2005). Many of these employment opportunities will occur in rural areas, which has the added benefit of stimulating economic growth in these areas (Golden & Handfield, 2014). Subsequently, capable employees will be needed to fill these positions, and the lack of a prepared workforce has been identified as a limitation to this growing field (Savolainen, Honkanen, & Vertainen, 2013). In response, bioenergy training programs are being created (Malone, Harmon, Dyer, Maxwell, & Perillo, 2014), and it is anticipated that the next decade will bring about increased education efforts, particularly at the undergraduate level (Klemow, 2015).

In a global status review of renewable energy education, Kandpal and Broman (2014) state that

> Design, development and dissemination of appropriate renewable energy technologies is important for meeting the growing energy requirement for economic growth as well as for improvement in the quality of human life…development and dissemination of appropriate renewable energy technologies would thus require an adequate number of well trained and competent personnel in all countries of the world (p.301).

Subsequently, “Education and training in the area of energy in general, and new and renewable sources of energy in particular, is therefore, of prime importance” (Kandpal & Broman, 2014, p.301). Bioenergy accounts for a large portion of renewable energy in many countries around the world, but, to date, there is inadequate peer-reviewed bioenergy-explicit curricula literature and educational programming available (Malone, Harmon, Dyer, Maxwell, & Perillo, 2014).

In China, the world leader in energy use and carbon emissions (Liu, Lund, Mathiesen & Zhang, 2011), 74 forestry governmental officials with at least 10 years of experience were surveyed about their practices and perceptions on the development of forest bioenergy in their country (Qu et al., 2012). In addition to concluding that future Chinese bioenergy industry development will require cooperation of government and enterprises, including collaboration on issues surrounding social, economic, and ecological functions, results of the survey “also indicate that bioenergy related education through different channels have [sic] to be implemented and improved in China so that the development of knowledge meets the demands of everyday practices” (Qu et al., 2012, p.60).

Because progressing from fossil fuels to biomass “is going to require science and engineering breakthroughs that can only be achieved through developing new opportunities in collaborative research and interdisciplinary education" (Shahbazi & Schimmel, 2006, p.1), a variety of domestic and international training programs and curricular changes have been implemented, although they are limited. For example, North Carolina A&T State University created new "Energy and the Environment" and biomass/bioenergy courses for undergraduates to take to fulfill university requirements. The intention is that students will learn to think critically about how to make bio-based industries more sustainable, and development of these courses involved experts from industry and agriculture. Materials were also developed to be appropriate for distance (i.e. eCampus) learning, to allow inclusion of a large number of geographically dispersed students (Shahbazi & Schimmel, 2006).

Since 2009, Michigan State University has offered an international short course on bioenergy with the goal of building human resources capacity, particularly in developing countries, because "education, capacity building, information, dialogue and networking are critical to better formulate appropriate policies, research, development, and outreach programs to address energy issues for sustainable development" (Ransom & Maredia, 2012, p.11). This training program covers technical, social, and agricultural aspects of bioenergy and exposes participants to cutting-edge research and the scientists who conduct it, and also presents opportunities for collaborative research (Ransom & Maredia, 2012).

Many other countries have recognized the importance of establishing bioenergy training programs (Agar, Wihersaari, Jämsén, Ratia, & Päällysaho, 2011), and a Bioenergy Network of Excellence was established in Europe to reduce research overlap and make Europe a "world force" in the field (Sipilä & Wilén, 2012). In Europe, national policy directives and the growth of the bioenergy industry have resulted in rapid growth in the number of bioenergy higher education and training programs (Watkinson, Bridgewater & Luxmore, 2012). Because bioenergy processes are often dispersed, they require more labor than traditional fossil fuels, and subsequently create more jobs. For example, biofuels create 50-100 times more jobs than fossil fuels, electricity from biomass versus petroleum creates 10-20 times the number of jobs, and biomass-fueled heat production can provide twice the amount of jobs in Europe, and "to fill the demand it is essential that there are enough high quality advanced courses in place and enough students attracted to the bioenergy field" (Watkinson, Bridgewater & Luxmore, 2012, p.129). To increase interest and reduce concerns about obtaining jobs in a nascent industry, some training programs include a six-month industrial placement to provide students with job and networking experience with potential employers. Short courses are also being developed to provide professional development and expertise to bioenergy professionals, and also to deliver training to other bioenergy stakeholders such as farmers (Watkinson, Bridgewater & Luxmore, 2012).

Although the potential for and types of bioenergy vary among countries, it is generally agreed that in most countries certain socio-economic issues, namely local job creation, economic benefits, and reduced greenhouse gas emissions, can be motivational in increasing the percentage of bioenergy used in overall energy use (Domac et al., 2004). In order to investigate these issues and their impact on bioenergy use at local and international levels, an International Energy Agency was formed involving the following countries: Austria, Canada, Croatia, Ireland, Japan, Norway, Sweden, and Britain

(Domac et al., 2004). The ultimate aim of this "Task 29" group is to promote the use of bioenergy, and an important activity to this end is "Education and the contribution that education can make in removing different barriers for bioenergy around the world" (p.1). To reach this goal, the Task 29 group developed an interactive educational website that includes informative graphics, biomass calculation tools, discussion forums, self quizzes, and links to additional websites and articles (Domac et al. 2004) because "an improved awareness combined with significant educational efforts can make the difference needed to increase the use of bioenergy" (p.3).

If promotional efforts are successful, increased use of biomass for energy will result in considerable employment opportunities (Watkinson, Bridgwater, & Luxmore, 2012). As a result, "There will need to be considerable growth in the dedicated skills needed to support and develop the range of industrial sectors and thus a substantial demand for primary and secondary training courses" (p.128). In response, the Bioenergy Network of Excellence (NoE), which is a consortium of eight institutes from Finland, the Netherlands, the United Kingdom, Sweden, Poland, Germany, France, and Austria, performed a survey of bioenergy education and training in Europe. They were motivated to identify existing programs in Europe in order to evaluate and promote existing activities to improve NoE expertise, as well as build excellence in bioenergy higher education in Europe. Findings identified 65 Masters courses and 231 providers of PhD studies among the 27 EU members, Norway, and Sweden. They also surveyed a wide range of potential employers who confirmed that traditional science and engineering disciplines at the undergraduate level were the "best possible training" available to undergraduates before entering a graduate program. However, enrollment in these graduate programs is extremely low (Watkinson, Bridgwater, & Luxmore, 2012). Perhaps a more comprehensive undergraduate level training program, guided by a research-based curriculum framework, could increase interest and improve enrollment in these graduate programs.

In addition to providing factual education to improve job skills and knowledge, it is also necessary to generate interest among students to pursue careers in bioenergy (Malone et al., 2014). Because “existing material to promote bioenergy knowledge, awareness, and career aspirations usually targets youth from about $6^{th}$ through $12^{th}$ grades” (Sheer, Hall & Wright, n.d., p.1), and research indicates that to have the most effective impact on youth knowledge and skills, students should be reached at an earlier age (Bronfenbrenner, 2005), a bioenergy curriculum for grades K-2 has been developed in conjunction with The Ohio State University, Ohio Bioproducts Innovative Center, and 4-H Youth Development in Ohio (Sheer, Hall & Wright, n.d.). Utilizing the do-share-process-generalize-apply steps of Kolb’s (1984) experiential learning model, this K-2 curriculum adapted successful middle and high school programs and mapped them to K-4 national science education standards to be appropriate for K-2 students. This curriculum provides hands-on activities that cover the topics of bioenergy sources, bioenergy conversion, and bioproducts, and was designed to create interest and excitement about bioenergy in a positive learning environment. In addition to promoting bioenergy knowledge and career aspirations, the authors state that the curriculum “helps children begin to understand the concept of environmental sustainability and the significant role of bioenergy for providing long-term solutions to bring authentic environmental sustainability for future generations” (Sheer, Hall & Wright, n.d., p.3).

For a bioenergy industry to thrive, it is equally important to generate interest in bioenergy careers as it is to increase general awareness about energy options, because informed citizens will become future responsible energy consumers (Zografakis, Menegaki &Tsagarakis, 2008). For this reason, Halder et al. (2010) conducted a study of 495 Finnish 9th graders to investigate the impact that the source of bioenergy information (school, home, media) has on students' perceptions, attitudes, and knowledge regarding bioenergy. Results of this study indicate that to improve the utilization of bioenergy, both sufficient knowledge of bioenergy and a positive attitude towards it are necessary (Halder et al., 2010). Based on these findings, Zografakis, Menegaki and Tsagarakis (2008) also highlight the need to integrate modern renewable energy concepts into school curricula. A problem that Halder (2015) encountered with this goal is that oftentimes school teachers have limited knowledge of bioenergy, which leads to the subject being a low priority in their classes. Consequently, Halder (2015) recommends improving teachers' knowledge about the subject so they can more effectively teach it; therefore, an organized educational framework could likewise be useful for teacher training programs.

A USDA-funded project, Northwest Advanced Renewables Alliance (NARA), has developed teacher professional development programs to increase teachers' bioenergy literacy so they can teach energy concepts more effectively in the classroom (Eitel et al., 2015). NARA partners use place-based contexts and connect teachers with current scientific research projects to be used as resources for teaching in the classroom. Place-based learning ties local issues to broader environmental concepts (Greunwald, 2003) and makes global issues, such as climate change, more relevant to students (Somerville, 2010). To connect teachers to ongoing research in the field, NARA uses an outreach model that has been shown to increase public support for science, and also encourages improved decision-making (Varner, 2014). Two forms of the teacher training, a webinar version and an intensive workshop format, were both found to be effective models to increase teachers' energy literacy and support their ability to share new knowledge with their students (Eitel et al., 2015). In this case study, NARA, whose overall aim is to convert logging slash into jet fuel, utilized the U.S. Department of Energy's Energy Literacy Framework as a teaching and learning tool (Eitel et al., 2015). However, although general energy literacy is fundamentally important, because NARA is a bioenergy-related program, a bioenergy-specific education framework could prove more appropriate and valuable for bioenergy-related teacher training programs. A structured framework used to train teachers could also result in more consistent and standardized teaching of bioenergy concepts for students, as well as higher curricula quality overall, by providing desired learning outcomes specifically for bioenergy education (Casimiro, MacDonald, Thompson, & Stodel, 2009).

Although numerous countries on multiple continents recognize the importance of bioenergy education, there is very little literature available and a lack of consensus regarding what a bioenergy curriculum should include. Moreover, as illustrated by this description of existing programs, it is clear that although efforts are being made to establish bioenergy education programs, oftentimes the curricula are developed without a research basis. In other words, bioenergy education programs are often created based on what has been done previously for other grade levels, or with the expertise that is readily and locally available, but not necessarily based on empirical research findings. When there is a lack of research available to inform the development of curricula, it "results in curriculum development which [sic] is largely intuitive in nature without a cohesive strategy to guide developers towards goals which [sic] would facilitate the production of a citizenry competent to cope successfully with environmental issues" (Hungerford et al., 1980, p.42). Because bioenergy has many implications for the environment, particularly by providing alternatives to fossil fuels and mitigating climate change, it is necessary to establish a research-based curriculum framework for bioenergy education.

### *Interdisciplinarity in Higher Education*

Interdisciplinary understanding has been defined as

> the capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement – such as explaining a phenomenon, solving a problem, or creating a product - in ways that would have been impossible or unlikely though single disciplinary means" (Boix Mansilla et al., 2000, p. 219).

Complex problems, such as climate change and mitigation strategies, require the integration and synthesis of multiple fields, and interdisciplinary approaches to solutions are becoming increasingly common (Xu, Goswami, Gulledge, Wullschleger & Thornton, 2016). It is this integration that sets interdisciplinarity apart from cross- and multi-disciplinarity, as "interdisciplinarity should bring about a new understanding of a particular phenomenon, not simply a revised perspective regarding a disciplinary question" (Holley, 2009, p.29). When interdisciplinarity involves "a transgression against or transcendence of disciplinary norms" (Barry & Born, 2013, p.9), the term "transdisciplinary" is used. However, interdisciplinary, transdisciplinary, and interprofessional have been used synonymously in the literature regarding collaboration, or "a process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their own limited vision of what is possible" (Gray, 1989, p.5).

Interdisciplinary approaches enable a more comprehensive understanding of complex problems, and, subsequently, interdisciplinarity in higher education has earned increased interest (Newell, 2007). This type of education results in "boundary-crossing skills" such as "the ability to change perspectives, to synthesize knowledge of different disciplines, and to cope with complexity" (Spelt, Biemans, Tobi, Luning & Mulder, 2009, p.366). "Interdisciplinary teaching does not focus primarily on detailed factual knowledge, rather it focuses upon the development of core competencies for solving different kinds of problems" (Steiner & Posch, 2006, p.880). It draws on disciplinary perspectives and integrates their insights to construct a more comprehensive understanding of the issue of concern (Newell, 2007).

Rhoten, Boix Mansilla, Chun, and Klein (2006) describe interdisciplinary education as

> a mode of curriculum design and instruction in which individual faculty or teams identify, evaluate, and integrate information, data, techniques, tools, perspectives, concepts, or theories from two or more disciplines or bodies of knowledge to advance students' capacity to understand issues, address problems, and create new approaches and solutions that extend beyond the scope of a single discipline or area of instruction (p.3).

Critical thinking, as well as developing, applying, and communicating innovations, results from interdisciplinary education (Holley, 2009). Due to the inherent complex and interdisciplinary nature of the field of bioenergy, and the collaborative innovations required to provide solutions, it is appropriate that a bioenergy curriculum be interdisciplinary also.

The National Science Foundation has stated that “Environmental challenges are often exceedingly complex requiring strengthened disciplinary inquiry as well as broadly interdisciplinary approaches that draw upon, integrate, and invigorate virtually all fields of science and engineering” (NSF, 2000, p.xi). Moreover,

> Education strategies are being considered…to prepare a new professional to feel comfortable in a multidisciplinary framework…Such an approach would enable graduates to apply their learning to the needs of the real world and real problems. Cross disciplinary education changes students’ awareness of issues and methods beyond their own disciplinary inquiry, enabling them to explore the relationship among these issues and encouraging students to view their studies from a broader social and ecological perspective that takes into account human values and environmental, social, and economic sustainability (www.ncseonline.org).

Interdisciplinarity has been critiqued or dismissed by some due to the diluted expertise that may result, as well as the time required to create effective interdisciplinary programs (Nissani, 1997). However, clearly there is value in investing the effort needed for interdisciplinary education, particularly for complex subjects that are comprised of a variety of disciplines, such as bioenergy.

### *T-shaped Professionals*

Although first coined in the field of computing by David Guest (1991), the term T-shaped person is now used in a variety of fields to describe someone who possesses both the depth of knowledge in a specific discipline, as well as the breadth (Figure 1.2) of complex communication skills required to collaborate with other experts to solve problems (Donofrio, Spohrer, & Zadeh, 2010).

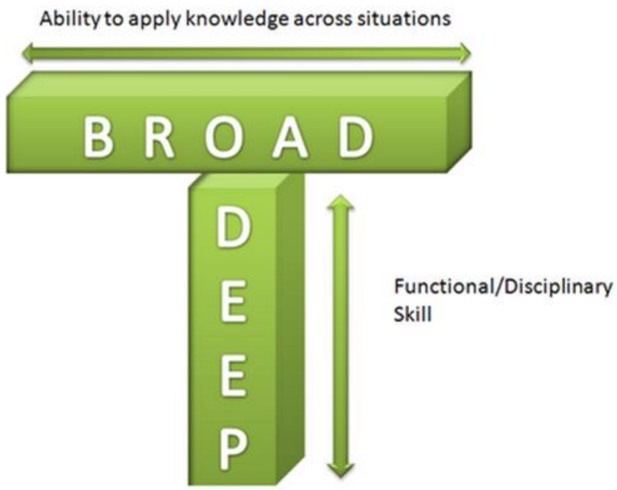


*Figure 1.2*. T-shaped person.
Source: http://smitpatel.com/entrepreneurs-should-be-t-shaped.

Other words used to describe this type of employee include "well-rounded", "variation of a Renaissance Man", and "hybrid", referring to the combination of technical expertise, business knowledge, and management skills (Palmer, 1990). The term "versatilist" has also been used and refers to

> people whose numerous roles, assignments, and experiences are enabling them to synthesize knowledge and context to fuel business value. Versatilists are applying their depth of skills and experiences to a rich scope of situations and challenges and implementing their cross-organizational insight…to fill competency gaps" (Morello, 2005, pp.12-13).

However, these T-shaped workers are not analogous to a "jack of all trades", but instead can be seen as having a specialization that is "empathetic" to how their core competency fits in the broader landscape of disciplines (Brown, 2007). This empathy "enables one to work alongside those disciplines, to understand their languages, to build upon ideas from those disciplines and to succeed within the systems that bring those disciplines together (Felmingham, 2013, p.8).

Traditionally, universities train graduates to be specialized in a specific discipline, but rapidly changing technologies and markets can cause problems for these narrowly-focused "I-shaped" professionals (Donofrio, Spohrer, & Zadeh, 2010). Subsequently, companies in the fast-paced cutting-edge technology and business fields are advocating for T-shaped professionals. For example, IBM worked with universities, government agencies, and industry to develop the recently recognized Service Science Management and Engineering (SSME) sector, which assists in creating T-shaped innovators (Maglio, Srinivasan, Kreulen, & Spohrer, 2006). T-shaped professionals are desirable in the computing, SSME, and medical fields, and the inherent hi-tech and business-related aspects of the field of bioenergy suggest they are desirable in the bioenergy industry as well. Although the following quotation refers to the field of engineering, it is applicable to many complex systems and real-world problems and provides a concrete example of the benefits of T-shaped employees:

> What follows is a typical profile for a successful integration team. In general, the members are the foundation of a system-focused approach to R&D. They possess a T-shaped combination of skills: they are not only experts in specific technical areas but also intimately acquainted with the potential systemic impact of their particular tasks. On the one hand, they have a deep knowledge of a discipline like ceramic materials engineering, represented by the vertical stroke of the T. On the other hand, these ceramic specialists also know how their discipline interacts with others, such as polymer processing — the T's horizontal top stroke (Iansiti, 1993, p.139).

In other words, T-shaped professionals have both a specific specialization, as well as broad knowledge of a range of other disciplines, including communication skills. As stated by a top design firm CEO that actively recruits T-shaped people, "they are able to explore insights from many different perspectives…that point to a universal human need"

(Brown, 2005, p.3). In short, educating more T-shaped people can “improve the performance of multidisciplinary teams (which apply discipline knowledge) and interdisciplinary teams (which apply and create new knowledge)” (Donofrio, Spohrer & Zadeh, 2010, p.137).

In a list of five principles developed to catalyze successful interdisciplinary collaboration, Brown, Deletic and Wong (2015) specifically recommend developing T-shaped researchers because of their ability to see beyond disciplinary boundaries and appreciate the approaches and theories of other disciplines. The appreciation for other viewpoints enables T-shaped people to actively engage with other disciplines, which leads to constructive conversations (Brown, Deletic, & Wong, 2015). Subsequently, these conversations may lead to solutions that individual specialists may not have discovered on their own (Madhavan & Grover, 1998). People with T-shaped skills are particularly valuable for creating new knowledge because with both breadth and depth, they can incorporate a variety of knowledge resources to develop solutions (Leonard-Barton, 1995).

Supporters of developing T-shaped professionals also believe that with today’s fast-paced technology development, the need for some specializations may be eliminated, and T-shaped professionals will be less costly to reskill and place in alternative positions (Donofrio, Spohrer & Zadeh, 2010). Conversely, critics claim that this idea of a T-shaped person is not a new concept, and that really what is needed is people with more experience, whatever “shape” they may be. It has also been noted that organizations will always require a broad array of skills, and that a preference for T-shaped workers could unintentionally minimize or segregate specialists that make important contributions , but who are more I-shaped (Buxton, 2009). However, these arguments are not so much against the creation of T-shaped professionals as they are for the incorporation of many types of professionals in a single organization (Donofrio, Spohrer & Zadeh, 2010). The biggest criticism and roadblock, then, is the cost of creating these T-shaped workers vs. I-shaped workers (Buxton, 2009).

Because there is currently a very small body of literature about the idea of T-shaped workers, Donofrio, Spohrer and Zadeh (2010) cite the following related empirical studies that "make clear that two primary dimensions of superior performance are complex communications (breadth) and problem solving (depth)" and "begin to lay a foundation for …the benefits of a larger ratio of T-shaped professionals in and across interconnected organizations" (p.3):

- Using a simulation model involving computational organizational theory, it was found that when there is variable demand in an organization, performance increases as the ratio of generalists (T-shaped workers) increases, and the more demand varies, the more generalists can increase performance over solely I-shaped specialists (Cataldo, Carley & Argote, 2001).
- Using 30 years of economic trends related to job descriptions, it was shown that while computers both create and eliminate jobs, the jobs created are higher-skilled while the jobs eliminated are lower-skilled occupations. Based on this finding, the researchers recommend preparing the population for the higher-skilled jobs that require the depth of problem

solving and computer expertise, as well as the breadth of interpersonal communication skills (Levy & Mernane, 2004).

- Using social science methods to investigate the nature of expertise across a variety of professions, Collins and Evans (2002) concluded that experts possess both “interactional expertise”, or complex communication abilities, as well as “contributory expertise”, or deep problem solving capabilities. They also claim that to be competent in both, traditional book learning is not adequate, and that social interactions with more knowledgeable and experienced professionals is required (Collins & Evans, 2002).

Finally, in reference to many large corporations, Hansen and von Oetinger (2001) state that many don’t take full advantage of the wealth of expertise distributed among the various departments of the organization. “Because they tend to rely on centralized knowledge-management systems…they're not very good at transferring implicit knowledge, the kind needed to generate new insights and creative ways of tackling business problems or opportunities” (Hansen & von Oetinger, 2001, p.106). In response, Hansen and von Oetinger (2001) recommend T-shaped management to help companies benefit from their inherent knowledge. Specifically, T-shaped managers “increase efficiency by transferring best practices, improve the quality of decision making companywide, grow revenues through shared expertise, develop new business opportunities through the cross-pollination of ideas, and make bold strategic moves possible by delivering well-coordinated implementation” (Hansen & von Oetinger, 2001, p.106). While noticeably beneficial for managers, these characteristics would also be advantageous for many bioenergy employees to possess.

### *Experiential Learning*

Experiential learning has been defined as beyond-the-classroom “experiences (internships, etc.) that provide students with the opportunity to gain transferrable work experience before graduation” (Spencer & Perry, 2015, p.27). According to Dewey (1938), all learning is experiential, but not all experiences are educational. What distinguishes experiential learning from other types of learning is that it directly exposes students to the “phenomena” studied in the classroom, while also requiring learners to analyze the experience and reflect on it (e.g. Barrett, 2007). This combined exposure and reflection results in gains in new knowledge and skills (Lewis & Williams, 1994). Kolb, who is recognized for his experiential learning theory, describes experiential learning as "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience"(1984, p. 41). In addition to helping students gain transferrable work-related skills and knowledge, research findings (Hurst, Thye, & Wise, 2014) suggest that these experiences also “provide opportunity to interact with industry professionals; and provide opportunity to refine communication and networking skills” (p.61). It has also been found that these opportunities allow for “ownership of a real-world project” and development of teamwork and collaboration skills (Thiry, Laursen, & Hunter, 2011). Another benefit of these experiences is that they allow students to explore a variety of career options, which not only helps them discover their personal interests, but also helps them “find out [if] it is something [they] don’t care about” (Spencer & Perry, 2012, p.200). Specific to

Science, Technology, Engineering, and Mathematics (STEM) careers, Crowe and Brakke (2008) assert that undergraduate experiential learning can increase student motivation, graduation rates, and entry into graduate degree programs.

Green, Graybeal, and Madison (2011) also found that these experiential learning opportunities enable students to make connections to their coursework, leading to students being more engaged in the classroom, which subsequently leads to more engaged employees (Ray & Kafka, 2014). This result has recently been recognized by employers, who are beginning to consider experiential learning activities a necessity for new hires (Spencer & Perry, 2015). In fact, in the 2012 Annual Job Outlook Survey, the National Association of Colleges and Employers found that 73.7% of employers had a preference for recent graduate with this type of experience (NACE, 2011). These experiential learning experiences are considered more valuable to employers than major, coursework, grade point average, and reputation of the educational institution from which the degree was obtained (Thompson, 2014). For these reasons, it would be beneficial to incorporate experiential learning experiences, in the form of research, internships, service-learning, outreach, and/or other activities, into a comprehensive bioenergy educational program.

### *Undergraduate Research Experiences*

Undergraduate research experiences (UREs) have been recognized as effective forms of experiential learning (Gilbert, Banks, Houser, Rhodes, & Lees, 2014). In the 1960s, the National Science Foundation (NSF) first began providing funds to research universities that enabled undergraduates to spend a summer in an active research lab

(Taraban, 2008). Based on anecdotal evidence of the benefits of UREs gleaned from participants (students and faculty mentors), the NSF then created the Research Experiences for Undergraduates (REU) program in 1987, which demonstrated the NSF's support for and recognition of the importance of these types of programs. Once the influential Boyer Commission Report (1998) claimed that undergraduate students should be encouraged to engage in the research and discovery process, other national organizations, such as the Howard Hughes Medical Institute (HHMI) and the National Council for Undergraduate Research began to support undergraduate research as an important part of learning at the university level (Lopatto, 2003).

Since then, a variety of empirical studies have investigated the benefits students gain through an undergraduate research experience, which is defined as "an inquiry or investigation conducted by an undergraduate that makes an original intellectual or creative contribution to the discipline" (Hu et al., 2008, p. 6). According to Lopatto (2003), in order to be successful, these undergraduate research experiences should involve the student in as much of the research process as possible, including, but not limited to, reading scientific literature, asking a researchable question, designing some part of the project, using reproducible lab techniques, and communicating significant findings orally or in writing, preferably at professional conferences.

A successful undergraduate research experience results in many gains for the student, such as increased self-efficacy, thinking like a scientist, clarification of and enhanced preparation for career and/or graduate school goals, ability to work both independently and as part of a team, and a variety of other skills such as time management, organization, communication, and using technology (e.g. Seymour, 2004;

Guterman, 2007). Studies on undergraduate research experiences are often framed by Vygotsky's (1978) theory of social development, which includes the theme that learners have a "zone of proximal development (ZPD)." This constructivist theory suggests that social interaction plays a critical role in cognitive development processes, and that the ZPD is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978, p.86). This "scaffolding," a term that has become synonymous with ZPD in the literature (Wood & Middleton, 1975), can occur with any More Knowledgeable Other (MKO), or someone who has a higher ability level than the learner, with respect to a particular task or concept (Vygotsky, 1978). In the case of undergraduate research experiences, the MKO is usually the faculty mentor, but may also be other people in the lab, such as graduate students, research assistants, and other undergraduate researchers.

Constructivist beliefs differ greatly from the traditional learning model in which a teacher 'transmits' information to students through lecture and reading assignments. Constructivism, where the learning is learner-centered, focuses on the process of finding a workable answer, based on evidence, rather than memorizing and replicating an objective "right" answer. Consequently, constructivism aligns well with the research process and UREs, and research with undergraduate students has been referred to as "the purest form of teaching" (Gentile, 2000) because the research mentors or MKOs provide the structure or scaffolding that is essential to fostering competence (Zydney et al., 2002).

***Delphi Method***

This recognized, mixed-methods procedure is popularly defined as a technique used to "obtain the most reliable consensus of opinion of a group of experts…by a series of intensive questionnaires interspersed with controlled feedback" (Dalkey & Helmer, 1963, p.458), and has been employed in a variety of curriculum-oriented investigations (e.g. Osborne et al., 2003; Rossouw, Hacker, & Vries, 2011). Delphi operates on the principle that "several heads are better than one in making subjective conjectures about the future…and that experts will make conjectures based upon rational judgment rather than merely guessing…" (Weaver, 1971, p.268). Wellman (2003) asserts that "complex, ill-defined problems often can be addressed only by pooled intelligence" (p.31), and groups have been shown to regularly outperform individuals in making judgements (Hill, 1982).

The Delphi method facilitates an efficient group dynamic process, and is differentiated from similar practices such as Nominal Group Technique (also referred to as estimate-talk-estimate) and focus groups by incorporating the following four characteristics: 1) anonymity among panel experts; 2) multiple iterations of group responses; 3) controlled, interspersed feedback to participants; and 4) statistical analysis of the group response (von der Gracht, 2008; Rowe & Wright, 1999). The Delphi technique was conceived in the 1950s by the Rand Corporation (Sackman, 1974), a research institution that focused on national security issues. It was initially used to reach consensus among experts in economics, physics, systems analysis, and electronics to determine the appropriate number of atomic bombs needed by the United States Air Force for a unique military scenario (von der Gracht, 2008). According to Rieger (1986), the method has gone through a variety of stages to become rigorous enough to be published in a high-quality academic journal such as *The Journal of Research in Science Teaching* (Osborne et al., 2003; Kloser, 2014). It was kept secret and used exclusively by the military in the 1950s; during the 1960s, Delphi was declassified and introduced to the public; it spread to Europe and Asia between 1970-1975 and became a popular forecasting tool in business; between 1975-1980 the technique was scrutinized and underwent critical reliability and validity evaluation; by 1986 Delphi showed stable application patterns and was accepted in science and practice; and by the 1990s it received increasing interest, and that trend continued, as demonstrated via an extensive literature review by Landetta (2006). The method is now applied to many fields where traditional statistical methods are not appropriate or even possible due to inadequate historical or technical data, therefore necessitating judgment via human input (Armstrong, 2001).

Combining both quantitative and qualitative approaches, the Delphi procedure provides a means to forecast future events in order to make suitable plans (Ludwig, 1997). The name Delphi stems from ancient times when people often sought advice regarding the future from an oracle at the popular Greek oracular site of Delphi (Gupta & Clarke, 1996). Delphi's sustained attractiveness as a planning and decision-making tool relies on its ability to efficiently elicit opinions from experts who bring knowledge, authority, and insight to the problem. Busy work schedules, in addition to high cost and time requirement of travel, can prevent face-to-face gatherings of people from multiple geographical locations, but Delphi provides a convenient, lower cost alternative to traditional brainstorming in order to generate ideas. Additionally, the anonymity among panel members, combined with the iterative format, reduces the bandwagon effect, facilitates the expression of honest opinions, and allows participants the freedom to change their minds between rounds without judgment (Rowe & Wright, 1999).

The Delphi technique is most useful and appropriate when: new trends and subsequent occupational needs are emerging (Toohey, 1999); there is minimal history available about the research issue (Murry & Hammons, 1995); perspectives from a range of experts who may be geographically separated is needed (Sackman, 1974). The method is considered as robust as case analyses and interviews (Ziglio, 1996) and was chosen for this study over traditional survey techniques because the nascent nature of the bioenergy field "limits the availability of a large enough random sample of experts to conduct traditional survey research and inferential analysis" (Choudaha, 2008, p. 63). The suitability of this approach over traditional surveys is further illustrated by contrasting both methods (Table 1.1).

Table 1.1
*Traditional Survey Research vs. the Delphi Method*

| **Criteria** | **Traditional Survey Research** | **Delphi Approach** |
|---|---|---|
| Goal of study | Generalization of results based on a large sample size determined by statistical significance | Exploration and consensus among experts who possess valuable knowledge in the field |
| Sample size | Random, statistical sampling techniques results in a representative sample of the population | Purposefully selected stakeholders are chosen for their expertise and willingness to participate |
| Data richness | Depends on questionnaire design and follow-up interviews that are often difficult to administer | Provides "richer data because of multiple iterations and participants' response revision due to feedback" (p.20) |
| Anonymity | Participants are usually anonymous to each other and the researcher | Respondents are usually anonymous to each other during the questionnaire process but not to the researcher |
| Attrition and non-response effects | Must be investigated for non-response bias | Can be minimalized by selecting experts who may implement the results and by sending reminders |

Source: Adapted from Okoli and Pawlowski (2004).

*Panel Selection*

The value of the Delphi approach for professional education is in "its capacity to capture those areas of collective knowledge that are held within professions but not often verbalized" (Stewart, 2001, p.922). The expert panel selection is a critical phase of the Delphi approach, and it has been suggested that the process is only effective if stakeholders who can benefit from the results of the study are involved (Clayton, 1997). For this reason, recruitment efforts for this study aimed for a heterogeneous mix of employers and educators in the bioenergy field from across the country, representing a variety of viewpoints. Panels of experts who have diverse perspectives produce more accurate judgments than experts who are more homogeneous (Lang, 1995; Wallsten, Budescu, Erev, & Diederich, 1997).

There is currently no established consensus in the literature regarding the appropriate number of experts for a Delphi panel, but a variety of empirical studies (Boje & Murnighan, 1982; Hogarth, 1977; Mitchell, 1991) have led to a generally accepted range of 5-30 experts. Low response rates and panelist attrition tend to be common issues with Delphi studies (Bardecki, 1984), and it has been reported that a mere 33% of participants who begin the study will continue through all rounds (Nowack, Endrikat, & Guenther, 2011). For this reason, a large number of experts are often initially invited, with the hope of retaining an appropriate number of participants throughout all rounds. A larger panel is preferred to maximize the diversity of responses, but it has been shown that beyond group sizes of 25, few new ideas are generated (Ashton, 2000). To increase participation, as an alternative to a monetary incentive to contribute, panelists may be given the opportunity to be identified as an expert at the conclusion of the study, as suggested by Bolger and Wright (2011). If the minimum number of panelists is not obtained through these initial efforts, participants may be asked to nominate additional suitable experts, resulting in a purposive, snowball sampling of participants (Clayton, 1997). Delphi has been criticized for having no agreed upon definition of "expert" (Baker, 2006), so in order to be considered an "expert" in a Delphi study, participants should meet predetermined requirements (Moore, 1987).

Dalkey and Helmer (1999) identify four main areas of criticism of the Delphi technique: 1) the lack of definition of "expert", 2) the opportunity for researcher bias, 3) the time commitment required of participants, and 4) the possibility of "sloppy" questionnaire design. In order to resolve these concerns as soundly as possible, the following precautions were taken for this study, which address each of the above criticisms, respectively: 1) in order to be considered an expert for this study, participants had to meet a predetermined list of qualifications determined by teaching or industry experience, peer-reviewed publications, and education level; 2) researcher bias for this study was not concerning because multiple coders were employed in the process; 3) the time requirement requested from panel experts was significantly reduced in the first Delphi study by limiting the number of open-ended questions to one, and in the second Delphi study by starting Round One with a list derived from the results of the smaller pilot study (i.e. experts did not have to think of and write down the listed items, so only time for adding additional items was required); 4) the opportunity for "sloppy" questionnaire design was reduced because the initial questionnaire was reviewed and tested by multiple people and then piloted during the first Delphi study.

**Purpose of the Study and Research Questions**

The overall goal of this project was to provide insight into bioenergy education and training priorities in order to produce appropriate employees who are capable of working effectively in the field of bioenergy. To accomplish this, the specific objectives were: 1) using the Delphi method, survey a panel of bioenergy experts, identified as either educators or employers, regarding the essential components of a college-level bioenergy curriculum; 2) qualitatively and quantitatively analyze the data to investigate whether educators' and employers' priorities are aligned; and 3) utilize Delphi findings and student feedback to assess the interdisciplinary bioenergy minor model at Oregon State University. Specifically, the main research question addressed is as follows: According to experts, what are the pertinent components of a college-level bioenergy curriculum? Additional research questions addressed include: (a) Which bioenergy curricula components are rated most important overall?; (b) Are there disparities between educators and industry employers when prioritizing topics in a college-level bioenergy education program?; (c) What does an example of an interdisciplinary minor in bioenergy look like?; (d) What do students in the program gain from participating in the bioenergy minor program at Oregon State University?

**Significance**

Similar to curriculum-oriented Delphi studies conducted by Osborne et al. (2003) for the nature of science and Rossouw et al. (2011) for engineering and technology education, the purpose of the Delphi components of this study was to generate a list of basic and broad, yet pertinent, bioenergy concepts to be used in the establishment of training programs and college-level curricula. The results represent the foundational knowledge that students should have in order to contribute prosperously to the field of bioenergy, according to a panel of experts from the United States. Because bioenergy covers topics from biodiesel and cellulosic ethanol, to algal oils and microbial fuel cells, it is difficult to produce a comprehensive list of all competencies expected from an employee in the bioenergy arena. Therefore, the results are intended to be used as a general guideline for the overarching topics that should be covered during training. Using this framework, institutions and training programs may adapt the learning content based on geographical location and technologies and industries growing in that region.

Although noteworthy empirical research exists pertaining to energy education, and even renewable energy (i.e. solar, wind) as a whole (Jennings, 2009), to date there is inadequate bioenergy-explicit curricula literature available (Malone, 2014). An extensive literature search exposes the fact that compared to other countries such as Ireland, Finland, and Taiwan (Guest, Healion, & Hoyne, 2003; Halder et al., 2010; Wang, Chen, & Lee, 2012), the United States is particularly lacking in this capacity. Bioenergy will play a significant role in the emerging global bioeconomy (Smáradóttir et al., 2014), and according to the White House's National Bioeconomy Blueprint (2013), education efforts are expected to "contribute broadly to the development of a bioeconomy workforce for the 21st century", "prepare the next generation to compete successfully in a bioeconomy" and "support America's ability to innovate in the global economy" (pp.34-35). At a time when the US government is funding bioenergy research and development projects with a substantial amount of public funds (USDA, FY2016), it is vital that these efforts be augmented and strengthened by providing students with a suitable education to ensure they are desirable, employable, and effective in their future careers. The establishment of a general bioenergy education framework can assist in providing tomorrow's bioenergy innovators the tools necessary to contribute to the advancement of this imperative, expanding discipline and support them and the United States for success in the forthcoming bioeconomy.

Because this inquiry began with a pilot study in 2014, followed by a similar study with a larger panel in 2015, it was possible to compare results and determine changes in priorities. For example, the economic feasibility of a successful bioenergy industry is affected by fluctuating oil prices, particularly lower natural gas prices that accompany the current ease of fracking (Amezaga, Bird, & Hazelton, 2013). Additionally, a larger, more diverse expert panel in the 2015 study enabled investigation into whether industry experts agreed with educational experts regarding which items were most essential (i.e. are students being taught what potential employers want them to know?). Finally, a case study of the bioenergy minor at OSU presents a model of how the Delphi results (essential curriculum components) have been incorporated into an interdisciplinary college-level program, including feedback from current students and graduates of the minor.

Taken together, the Delphi studies that established a curriculum framework, and feedback from students and alumni about an existing bioenergy education program, begin to lay a foundation for a model to effectively teach bioenergy at the college level, which could directly affect the quality of the workforce produced.

**Limitations**

It is acknowledged that Delphi results are dependent on the nature of the problem at the present time, and opinions may change with technological development and new research findings (McKenna, 1994). Delphi studies are also limited because participants are not randomly selected; instead, participants are sought based on their expertise in a given subject area. Therefore, although the quantitative results are valuable in prioritizing items, the intent of the numeric results is not to provide statistical inferences (Quendler & Lamb, 2016). However, given that the panel was chosen from academia, industry, and government organizations from across the country, results are transferrable (applicable to real life), but not generalizable (applicable to a population as a whole) (Firestone, 1993). Furthermore, the additional use of qualitative analysis provides a richer description of the bioenergy framework items than would have been possible using a list of concepts obtained from the literature for a strictly quantitative survey.

The researchers' personal backgrounds, assumptions, and perspectives on the topic may have also influenced the manner in which the data was interpreted and qualitatively coded. However, this limitation is addressed by having multiple independent coders, and by the iterative nature of Delphi, which serves as a form of member-checking to ensure the researchers understood the responses as intended by the experts (Engels & Kennedy, 2007).

**Definition of Key Terms**

- Bioeconomy: an emerging economy, driven by innovation and research in the biosciences, that has the potential to lead to healthier lives for Americans, lower healthcare costs, transformed manufacturing practices, and improved agricultural productivity to meet the needs of our growing population (White House, 2012)
- Bioenergy: energy derived from living or recently living biological sources (biomass)
- Delphi Method: a structured group communication technique that relies on a group of experts to provide opinions for the purposes of attaining consensus and forecasting
- Interdisciplinary: of or relating to more than one branch of knowledge; the integration of two or more disciplines to provide new knowledge and solutions to complex problems
- T-shaped Professional:  professionals that possess both the depth of knowledge in a specific discipline to solve problems, as well as the breadth of complex communication skills required to collaborate with other experts (Donofrio, Spohrer, & Zadeh, 2010)
- Undergraduate Research Experience (URE): "An inquiry or investigation conducted by an undergraduate that makes an original intellectual or creative contribution to the discipline" (Hu et al., 2008, p. 6).  Specific to the requirements to obtain a minor in bioenergy at OSU, for the purposes of this dissertation, a URE also involves preparation of a written thesis, and verbal dissemination of findings at a public seminar.

# CHAPTER 2

## Determining Essential Components of a College-level Bioenergy Curriculum in the United States Using the Delphi Technique

Kimi Grzyb[1], Brian D. Hartman[2], and Katharine G. Field[3]
Oregon State University, Corvallis, Oregon, USA
[1]*Environmental Sciences*, [2]*Science Education*, [3]*Microbiology*

### Abstract

In order to develop bioenergy into a viable industry capable of providing valuable energy and employment, there is an immediate need for a workforce prepared for the impending challenges of this emerging, interdisciplinary industry. To meet this need, it is necessary to identify and prioritize the topics that should be included in a college-level bioenergy curriculum. We implemented a three-round Delphi study to determine components of a college bioenergy curriculum in the US, by establishing consensus among a panel of American bioenergy experts. Round One consisted of a single open-ended question: Keeping in mind the future of a commercial bioenergy industry, what content knowledge should a student have upon completion of a college-level bioenergy curriculum? Responses were qualitatively coded into themes, and experts were asked to rate the importance of each theme using a five-point Likert-type scale during subsequent rounds. The final round resulted in 13 themes: Energy Basics, Types of Bioenergy, Environmental Impacts (including Life Cycle Analysis), Current Technologies, Societal Issues, Logistics, Policy, Biomass Composition, Non-Bioenergy-Specific Fundamentals, Biomass Production, Conversions, Bioenergy Market, and Business-Related Knowledge. Results will be used to bolster the existing bioenergy education initiative at Oregon State

University, and can provide guidance to other institutions in the US and abroad interested in developing similar bioenergy education programs.

**Key Words:** renewable energy, bioenergy education, Delphi technique, curriculum development, bioeconomy

## Introduction

Bioenergy could play a vital part in a successful global bioeconomy (Smáradóttir, 2014), defined as "an economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources" (McCormick & Kautto, 2013, p.2589). A prosperous bioeconomy has the potential to lead to healthier lives, lower healthcare costs, transformed manufacturing practices, and improved agricultural productivity to meet the nutritional needs of the population (White House, 2012). An important, additional benefit of a successful bioenergy industry is the numerous employment opportunities it will create, especially in rural areas (Becker, Skog, Hellman, Halvorsen, & Mace, 2009; Mathews, 2008). Over 40 nations have promoted the bioeconomy as a way to combat the challenges of sustainable global development (Communiqué, 2015).

Worldwide energy consumption is predicted to nearly double between 1990-2030 (Taylor, Govindarajalu, Levin, Meyer, & Ward, 2008), and there is a need to find feasible solutions to meet this demand. Heavy reliance on fossil fuels for energy needs has resulted in accelerated climate change, compromising global environmental health and national independence and security. Much research is currently being conducted to improve the process of converting the solar energy stored in biomass to a form that can be utilized efficiently and cost-effectively to the benefit of society and the environment (Warnmer, 2007). New technologies that advance conversions of biomass to biofuels, coupled with the instability of oil prices, strongly suggest that the importance, applicability and utilization of bioenergy will continue to escalate (Pasztor & Kristoferson, 1990; Popp, Lakner, Harangi-Rákos, & Fári, 2014). In fact, from 2005 to 2011, global demand for biofuels increased four-fold to approximately €60 billion (Scarlat, Dallemand, Monforti-Ferrario, & Nita, 2015).

As the bioenergy industry and job market continue to grow (White & Walsh, 2008), a well-trained workforce capable of implementing innovations and meeting impending challenges will be required. Yet both worldwide and in the US, there is a severe deficiency in training programs and courses dedicated to bioenergy (Ransom & Maredia, 2012). The lack of designated training programs for bioenergy suggests that many of the graduates currently entering this growing field are not being specifically educated about bioenergy prior to joining the workforce. Because "a vibrant bioeconomy depends on the education and skills of its workers" (White House, 2012, p.33), the US National Bioeconomy Blueprint (2012) includes updating training programs as one of its five strategic objectives. Internationally, interdisciplinary collaboration among educators has been identified as one of the five bioeconomy cornerstones (El-Chichakli, von Braun, Lang, Barben, & Philp, 2016).

However, the bioenergy field requires a unique set of skills that is not typically covered in traditional undergraduate education. It requires knowledge of energy as a foundation, but it also requires general knowledge in a variety of other subjects such as chemistry, biology, engineering, policy, and economics. This highly interdisciplinary field necessitates the integration of multiple disciplines, highlighting the need to organize the many aspects into a structured educational framework.

Because bioenergy is a nascent industry and limited college-level bioenergy education programs have been established, little research has been done to determine what a curriculum should include. In the past, curricula for other sectors of environmental education, such as conservation education, have been ineffective, because curricular components were chosen via "intuition" (Hungerford, Peyton, & Wilke, 1980). When there is a lack of research available to inform the development of a curriculum, it "results in curriculum development which is largely intuitive in nature without a cohesive strategy to guide developers towards goals which would facilitate the production of a citizenry competent to cope successfully with environmental issues" (Hungerford et al., 1980, p.42). Bioenergy has many implications for the environment (e.g. Suttles, Tyner, Shively, Sands, & Sohngen, 2014), particularly by providing alternatives to fossil fuels and mitigating climate change. Therefore, it is crucial to establish a research-based educational framework for appropriate bioenergy employment preparation.

The Delphi research methodology has been successfully employed in a variety of curriculum development and workforce training investigations (e.g. Kloser, 2014; Rossouw, Hacker, & Vries, 2011; Osborne, Collins, Ratcliffe, Millar & Duschl, 2003). This recognized, mixed-methods procedure is popularly defined as a technique used to attain consensus from experts using survey iterations and selective feedback (Dalkey & Helmer, 1963). Combining both quantitative and qualitative approaches, the Delphi procedure assists in forecasting upcoming needs in order to make suitable plans for the future (Ludwig, 1997). Delphi's sustained attractiveness as a planning and decision making tool stems from its ability to efficiently elicit opinions from experts who bring knowledge, authority, and insight to the problem (Gupta & Clark, 1996). Busy schedules and travel costs can prevent face-to-face gatherings of people from multiple locations, but Delphi provides a convenient, lower cost alternative to traditional brainstorming (Dalkey & Helmer, 1963). Additionally, anonymity among panel members, combined with the iterative format, reduces the bandwagon effect, facilitates the expression of honest opinions, and allows participants the freedom to change their minds between rounds without judgment (Rowe & Wright, 1999).

The Delphi technique is useful and applicable when new trends and subsequent occupational needs are emerging (Toohey, 1999). The method is applied when traditional statistical methods are not appropriate or possible due to inadequate historical or technical data, therefore necessitating judgment via human input (Rowe & Wright, 1996). Given the current developmental stage of the bioenergy field, Delphi provides an appropriate forecasting technique to cultivate a consensus among experts to improve workforce education efforts.

This study aimed to determine the essential components of a college-level bioenergy curriculum. Results can be used to bolster existing bioenergy education initiatives and provide guidance to administrators interested in developing new programs. The study took place in the US, but using this framework, international institutions and training programs can adapt the learning content based on geographical location and technologies and industries growing in their region.

## Materials and Methods

A three-round Delphi study (Okoli & Pawlowski, 2004) was implemented to establish consensus among a panel of US experts regarding necessary components of a college-level bioenergy curriculum. For more established areas of study, a review of the literature is often utilized to inform the first round of Delphi questionnaires (Franklin & Hart, 2007). However, due to the exploratory nature of this research and lack of literature available, the traditional open-ended questionnaire was used (Murry & Hammonds, 1995). The study was conducted in accordance with Oregon State University's Institutional Review Board requirements. The nature of the research was described in Round One, and only those participants that selected "agree" to the online informed consent information were allowed to complete the survey. Participants were given approximately two weeks to complete each round, and reminders were sent after one week and again one day before the deadline for each round.

### *Panel Selection*

The expert panel in this Delphi study was composed of 12 diverse professionals with extensive experience in the areas of bioenergy research, education, and industry. Initially, in May 2014, 169 potential participants were invited based on their affiliation with the United States Department of Agriculture (USDA) consortium, Advanced Hardwood Biofuels Northwest (www.hardwoodbiofuels.org). They were asked to extend the invitation to additional suitable experts, resulting in a purposive, snowball sampling of participants. To be eligible as an expert for this study, participants had either (a) a publication in a peer-reviewed, bioenergy-related journal; (b) at least two years of experience teaching bioenergy classes at the college level; (c) three years of bioenergy industry experience; and/or (d) a PhD in a related field.

Recruitment resulted in 42 interested experts who were then randomly assigned to either an elementary through high school (K12) (20 participants) or college-level (22 participants) curriculum Delphi panel. Only the college-level results are reported in this paper. Of the 12 experts who joined the college-level panel in Round One, eleven members (92%) remained through Round Three for this study. Of the initial employers, educators, researchers, administrators, and government agents that made up the expert panel, one was female and seven hold PhDs in associated fields. They also represent states from across the US: Oregon, California, Colorado, New York, and Maryland.

### ***Delphi Rounds***

#### *Round One*

In May 2014, panelists were asked to respond to a single open-ended question: "Keeping in mind the future of a commercial bioenergy industry, what content knowledge should a student have upon completion of a college-level bioenergy curriculum?" The questionnaires for all rounds were delivered electronically using the survey software package Qualtrics (Qualtrics, Provo, UT). Responses from Round One were qualitatively coded by two members of the research team, using NVivo (QSR International Pty Ltd, Victoria, Australia), until 100% inter-rater reliability was reached.

The resulting 14 themes from Round One became the questionnaire items for subsequent rounds.

*Round Two*

In June 2014, participants were presented with the 14 themes and asked to rate the importance of including each theme in an undergraduate bioenergy curriculum, using a five-point Likert-type scale (1=Non-essential to 5=Essential). Included with each theme title were a theme summary and anonymous example panel responses (Figure 2.1) to increase transparency regarding how the themes were determined. For each theme, experts were also given the opportunity to provide additions, modifications, clarifications, and/or justifications.

**<u>BIOMASS PRODUCTION</u>**

Summary: Students should understand the methods involved with producing commercial quantities of biomass.

Example panel responses: Agriculture; silviculture; forestry; aquaculture; crop management; harvest; soil science; water conservation; erosion control; soil/plant/atmosphere interfaces; plant pathology; pest management; how to determine the amount of biomass that can be sustainably supplied from a given region

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | × No Opinion |
|---|---|---|---|---|---|---|
| **Biomass Production** | ○ | ○ | ○ | ○ | ○ | ○ |

*Figure 2.1*. Example of theme title, summary, example responses, and rating scale presented to experts in Round Two.
Source: Author's own.

### *Round Three*

In August 2014, experts were shown the panel's mean rating and standard deviation from Round Two, as well as the title and summary for each theme, and again asked to rate them on the five-point scale. To encourage consensus (e.g. Rossouw et al., 2011), participants were asked to provide an explanation if they deviated more than one point from the panel's mean score. Again, panel members were asked to provide comments, so this final round also served as a type of member-check that ensured the researchers had correctly interpreted and categorized the experts' responses (Engels & Kennedy, 2007). Eleven of the 12 experts responded.

## ***Analysis***

Due to the non-random selection of experts and non-independence and non-reproducibility of the study, statistical inference cannot be drawn, and therefore analysis was limited to descriptive statistics (Quendler & Lamb, 2016).  Mean ratings were used to determine the importance of each item, while standard deviation was used to represent consensus. Stability was also calculated in the final round and was defined as a difference of 33% (one third) or less in the expert panel's mean ratings between Rounds Two and Three (Osborne et al., 2003). Stability is referred to as "the consistency of answers between successive rounds of the study", and all stability values fell within an acceptable range (Dajani, Sincoff  & Talley, 1979).

# **Results**

## ***Delphi Rounds***

### *Round One*

This round served as a brainstorming session. Response length ranged from a few sentences to over 1,100 words; there was no limit to the number of items an expert was allowed to list. Participants took between three and sixty-three minutes to complete the survey. After coding, the themes resulting from Round One were: *Types of Bioenergy*, *Logistics*, *Societal Issues*, *Bioenergy Market*, *Environmental Impacts*, *Biomass Production*, *Biomass Composition*, *Conversions*, *Energy Basics*, *Current Technologies*, *Life Cycle Analysis*, *Policy*, *Business-Related Knowledge*, and *Non-Bioenergy-Specific Fundamentals*.

*Round Two*

All twelve of the experts from Round One completed Round Two. There were multiple panel comments from this round about the interrelatedness of two of the themes, *Life Cycle Analysis* (*LCA*) and *Environmental Impacts*. For example, experts stated that "LCA and the environmental theme overlap significantly", and "LCA goes hand-in-hand with Environmental Impacts…it's essentially the same concept, but more in depth." Based on these comments, the researchers included *Life Cycle Analysis* within the theme of *Environmental Impacts*, resulting in 13 themes to be rated in Round Three. Upon completion of Round Two, twelve of the original fourteen themes had a mean of ≥4 on the five-point scale (Table 2.1), signifying that the experts considered them important (Osborne et al., 2003). Of these twelve essential themes, nine had standard deviations of <1.0, which indicates a high level of consensus (Osborne et al., 2003) for these themes. Interestingly, 2 of the 3 themes with standard deviations >1.0, *Energy Basics* and *Environmental Impacts*, were among the three highest rated themes, receiving means of 4.5 and 4.33, respectively. Although the Delphi method lacks consensus in the literature regarding cut off scores (Kloser, 2014), this study used a mean of ≥3.6 out of 5, as done by Osborne et al. (2003), so all themes were included to be rated in Round Three (albeit two were combined into one).

Table 2.1

*Bioenergy Curriculum Framework Themes and Summaries with Ratings from Rounds Two and Three*

| | Round Two | | Round Three | |
|---|---|---|---|---|
| Theme Title/Summary | *M*[1] | *SD* | *M*[1] | *SD* |
| Energy Basics: Students should understand the fundamental principles of energy | 4.50 | 1.24 | 4.73 | 0.47 |
| Types of Bioenergy: Students should be familiar with a broad range of available and emerging types of bioenergy | 4.50 | 0.90 | 4.64 | 0.67 |
| Environmental Impacts (including Life Cycle Analysis): Students should be familiar with positive and negative environmental impacts related to bioenergy production and evaluate inputs and outputs to make informed decisions | 4.33 | 1.23 | 4.45 | 0.52 |
| Current Technologies: Students should be familiar with current energy production | 4.17 | 0.94 | 4.27 | 0.47 |
| Societal Issues: Students should recognize the societal consequences (pros and cons) resulting from a bioenergy industry | 4.08 | 0.90 | 4.27 | 0.47 |
| Logistics: Students should understand the planning, implementation, and coordination required for the bioenergy supply-chain | 4.08 | 0.67 | 4.18 | 0.40 |
| Policy: Students should be familiar with existing and proposed policies that influence the growth of the industry | 4.00 | 0.95 | 4.09 | 0.54 |
| Biomass Composition: Students should know the basic biomass components | 4.33 | 0.89 | 4.00 | 1.00 |
| Non-Bioenergy-Specific Fundamentals: In addition to the above-mentioned topics, students should also have fundamental coursework and skills (Biology, Chemistry, Math, Physics, Writing Skills, Ecosystems, Communication, Data Analysis/Statistics, Process Modeling) | 4.23 | n/a | 4.00 | n/a |
| Biomass Production: Students should understand the methods involved with producing commercial quantities of biomass | 4.42 | 0.79 | 3.91 | 0.94 |

Table 2.1 (Continued)

| | | | | |
|---|---|---|---|---|
| Conversions: Students should have scientific knowledge of converting biomass to intermediates and end products | 4.08 | 0.90 | 3.91 | 0.54 |
| Bioenergy Market: Students should be familiar with the current and projected bioenergy market | 3.92 | 1.00 | 3.73 | 0.65 |
| Business-Related Knowledge: Students should have a basic understanding of business management and strategy (Finance, Economics, Risk/SWOT Analysis, Return on Investment Calculations) | 3.75 | n/a | 3.65 | n/a |

Results of Rounds Two and Three. [1]Means on a 5-point scale of 1 "not essential" to 5 "essential."

*Round Three*

After Round Three, all themes had a mean rating of ≥3.6 and a standard deviation of ≤1.0, indicating consensus regarding the importance of including all themes in a college-level bioenergy curriculum. Although experts were given the opportunity, no new themes were added during Round Three.

*Energy Basics* consistently ranked (solely or tied) as the most important item to include in a college-level bioenergy curriculum (Table 2.1). One expert stated "The greatest source of wasted effort and outright foolishness in the bioenergy field arises from a poor understanding of energy production…", and another wrote "I don't know how you can teach bioenergy without assuring they know this stuff." Conversely, one participant was concerned that this topic was one that students should be familiar with before attending a bioenergy course, and thus should not be included in a bioenergy curriculum, because "having to start with this basic information…will result in many important topics not being covered". This may explain the large standard deviation in Round Two. However, in the end, this theme (mean=4.73) outranked *Types of Bioenergy* (mean=4.64), with which it was formerly tied (means=4.50) during Round Two, and the standard deviation dropped from 1.24 to 0.47, indicating overall consensus regarding its importance.

Similarly, *Types of Bioenergy* maintained a high rating throughout all rounds (Table 2.1). A panelist mentioned that “students will tend to focus on a narrow set or single type, so understanding the whole range of types is useful mainly for context”. However, it was also stated that “technologies are changing rapidly, and what seems hot in their first year of study may have failed, either in demonstration or commercial, before they even finish college”. Because these themes are general enough to be applied to many types of bioenergy, and “each existing and emerging type of bioenergy has a unique market and environmental impact” (expert panelist), another expert suggested that “students should know where to look for and how to evaluate emerging types of bioenergy”.

Based on panelist comments, *Environmental Impacts* was combined with *LCA* to form the theme titled *Environmental Impacts (including Life Cycle Analysis).* Additionally, the following two comments, “the general assumption is that bioenergy only has positive environmental impacts. That is not even close to being true. Students have to understand the possible environmental costs”, and “particular attention should be made to give a balanced perspective”, led the researchers to reword the theme summary from “Students should be familiar with environmental impacts related to bioenergy production” to “Students should be familiar with positive and negative environmental impacts related to bioenergy production and evaluate inputs and outputs to make informed decisions".

General understanding of *Current Technologies* was deemed important to provide "bioenergy's role in context" (expert panelist). Comments suggested that enough background knowledge was needed in order for graduates to make "a critical comparison of these to Bioenergy options", but specifics, such as "refining and petrochemical information is not that essential". An expert also claimed that "this comparison should be THE CENTRAL OBJECTIVE[sic] of the curriculum", expressing that all of the themes are sub-topics that are encompassed in this comparison and should support the primary goal of producing graduates that can propose and assess bioenergy alternatives to current technologies.

The theme *Societal Issues* was developed from comments about the changes (positive and negative) that will occur at local, national, and global levels. Some experts were concerned about how implementation of bioenergy plants in rural areas could affect the daily lives of residents in these areas, with increased "noise", "traffic", and "food and land prices". Although it was not mentioned specifically by experts, food security has been deemed "top priority" (El-Chichakli, von Braun, Lang, Barben, & Philp, 2016) in regards to a global bioeconomy, and could be included in this theme. Experts also mentioned "clarifying misconceptions" and "convincing people to choose bioenergy options". Increased awareness and education can increase bioenergy usage (Domac et al., 2004), which could lead to "increased national security" (expert panelist). Because of the range of local, regional, and national effects, it was suggested by an expert that "broad survey of these issues, perhaps with a few case studies where they are investigated in greater details should suffice."

Items listed during Round One, such as "a holistic approach to the supply chain" and infrastructure requirements such as transportation and storage of biomass, led to the creation of the theme *Logistics*. This was considered an important theme because "Logistics are key to the Value Chain as a whole, and also key to understanding the limitations of biomass vs. more logistically favorable resources" and "Without the complete supply chain biofuels do not enter the market."

Experts believed that the theme of *Policy* should be covered at the "overview level" and "Students should learn where to find this information as policies will probably change during their college study period". One expert had a particularly strong response about this theme:

> Policy has a huge effect on Bioenergy markets as a whole, as well as profound impacts all along the Value Chain. Policy needs to be emphasized not only because it is important, but also to make sure that no one graduates thinking that science, engineering, and logical thinking in general are even close to sufficient to develop a Bioenergy economy. The greedy, corrupt, ignorant, science-denying fools who inhabit political office at all levels, and the vested interests that buy and own them will have more to do with the development of this field than any underlying truth.

*Biomass Composition* encompassed cellulose, hemicellulose, lignin, ash, and moisture content. This was considered essential because "Understanding the chemistry of the feedstocks is important for understanding fuel conversion technologies". One expert expressed that this theme should be covered "As long as it is limited to the BASICS [sic] as stated in the Summary... Students will only need to get into detail as they pursue specific cases, either in the course of their education or later in their professional careers."

Experts listed a variety of *Non-bioenergy Specific Fundamentals*, such as chemistry, math, physics, ecology, writing and other communication skills, and data analysis capabilities. When rated individually, the topics considered most important by the experts were chemistry, communications skills, and data analysis. Although some of these topics can be practiced simultaneously within a bioenergy education context (e.g. writing proposals, giving presentations), much of the hard science would be likely to be covered in courses taken prior to a bioenergy course.

*Biomass Production* was a theme that emerged based on the example responses in Figure 2.1. During Round Two, more specific comments about the importance of this theme were communicated. For example, "The whole value chain is important, but nothing happens without BM production, and no value chain can be sustainable if the BM [biomass] production is not sustainable, nor economical if the BM production is not economical, etc., etc.; BM Production is "First among equals" in the Value Chain [sic]." Additionally, the "grade" or "quality" of feedstocks "can be impacted by storage, transport and seasonality as well", and "This needs to [be] amplified as it will have profound impacts on conversion processes."

Panel responses such as "biological, thermal, and chemical conversions"; "residence time and recycle/waste streams"; and "biomass processing" resulted in the theme, *Conversions*. Although it was considered important enough to be included in the framework (mean=3.91), one respondent was concerned that the "technical details may be overwhelming". Similarly, another expert stated "All students should have a basic understanding of conversion technologies and how different biomass resources are best suited for certain conversion pathways. However, this can quickly get too complex for students lacking a strong technical foundation." This shared concern about the intricate details of these processes may explain why this item was considered a lower priority.

Despite the notions that "Policy and natural gas availability drive the market [in the United States]", and "The market ultimately will drive renewable bioenergy implementation, and students need a sense of past, current and ongoing changes to that energy market picture," *Bioenergy Market* as a theme received a mean rating of <4 during both Round Two and Round Three (Table 2.1). The low rating of this item may be justified by the following expert quote: "These are going to vary greatly by geography and type of bioenergy…There is too much variety and variability to cover in any depth; if the students get a firm understanding of EXISTING [sic] energy markets under the "Energy Basics" topic, then they will have the background to dig into Bioenergy Markets as needed after graduation."

Although it fell within the predetermined cutoff values to be included in the framework, *Business-related knowledge* consistently ranked as the lowest priority theme throughout the study (Table 2.1). The general consensus was that risk, return on investment, and micro- and macroeconomics all play crucial roles in a bioenergy industry, particularly when projects are scaled up for commercial production. However, multiple experts expressed that this content knowledge should be learned in separate business courses. For instance, a unit "designed specifically to look at Bioenergy market economics would be reasonable", according to one expert, but general business-related information should be learned outside of a bioenergy curriculum.

### *Bioenergy Education Structure*

Although the initial open-ended question specifically asked about content knowledge, a variety of general comments were made about the structure of bioenergy education. These comments were not coded as curriculum content themes; however, they may be useful when establishing new educational programs. For instance,

> A college level bioenergy curriculum should have two broad learning objectives: 1. Become conversant in the terminology, technology, and issues associated with the advancement of bioenergy. 2. Develop a deeper expertise in one or more of the aspects of the bioenergy arena. The overall goal of a bioenergy curriculum should be to prepare students to be knowledgeable critical thinkers.

Similarly, it was also suggested that there should not be a traditional college degree in bioenergy, but, rather, that bioenergy should be offered as a specialization option that can be earned alongside a conventional major. These comments suggest that students should have both breadth and depth in their knowledge about bioenergy. Lastly, it was also noted that to apply the content knowledge to practice, "Some sort of multi-disciplinary 'Capstone' project would also be great, bringing together students from two or more disciplines on teams that would conduct a significant Design or Analysis Project [sic] in a Bioenergy field".

## Discussion

Bioenergy is gaining increased attention as a potentially sustainable solution to energy needs (Sagar & Kartha, 2007). As a result, a number of new university courses are being developed in this field (Malone, Harmon, Dyer, Maxwell, & Perillo, 2014). The results of this study demonstrate that bioenergy could be a formidable platform for interdisciplinary education due to the numerous subjects involved and the manner in which these disciplines must merge to create viable solutions and innovations to advance the field. As Malone et al. (2014) state, "The effectiveness of interdisciplinary courses is enhanced when diverse faculty and stakeholders are intimately involved in curriculum development…", and interdisciplinary education "encourages students to adopt a broad world view, facilitates a richer understanding of individual disciplines, enhances critical thinking, and provides students with the tools to develop solution-focused problem-solving skills" (2014, p.3). Moreover, McArthur and Sachs (2009) note the important role that university-level interdisciplinary programs play in producing workers who are able to innovate in order to solve problems related to sustainable energy. For these reasons, strong efforts were made to recruit a variety of expert bioenergy researchers, educators, and employers to participate in this study to determine the essential components of a college-level bioenergy curriculum.

Although noteworthy research exists pertaining to energy education, and even renewable energy (i.e. solar, wind) as a whole, to date there is inadequate bioenergy-explicit curricula literature available (Malone et al., 2014). Many countries are aiming to boost the bioeconomy (El-Chichakli, von Braun, Lang, Barben, & Philp, 2016), including the US, which has funded bioenergy projects with a substantial amount of public funds (e.g. through US Department of Agriculture and Department of Energy). Thus it is vital that these efforts be augmented by providing current students, who will become future leaders, with suitable, rigorous curricula to ensure they are supported for success.

However, due to the complex and interdisciplinary nature of the field of bioenergy, attempting to create a focused, effective, college-level curriculum may prove to be intimidating and difficult for individual instructors. By utilizing expert knowledge from a variety of bioenergy-related fields (e.g. feedstocks, conversions, policy, business) from across the country, we have established a general bioenergy curriculum framework that provides a starting point for institutions looking to launch educational programs.

### *Limitations and Implications for Future Research*

Initially, only individuals affiliated with the Advanced Hardwood Biofuels NW consortium were invited to participate in this study. Although additional experts were invited as a result of snowball sampling, the majority of the expert panel was comprised of researchers from the Pacific Northwest of the US, and only one female participated. The size of our expert panel was relatively small. Studies have found that this size panel is sufficient when experts represent heterogeneous areas of expertise; smaller heterogeneous Delphi panels have been equally effective in generating ideas as larger, homogeneous groups of experts (Linstone & Turoff, 1975). However, to obtain the most inclusive insight, best efforts should be made to obtain a larger panel for future research, including more females, as well as more stakeholders from industry and government agencies from diverse locales, including international sites.

Since the bioenergy arena is continually changing, the results are dependent on the nature of the problem at the present time, and opinions may change with technological advancements and new research developments (McKenna, 1994). The findings presented here represent the viewpoints of experts involved in the field in 2014. Because the market is highly influenced by policies and petroleum prices, expert perspectives and priorities may change as more bioenergy technologies attain commercial status.

**Conclusion**

The purpose of this study was to generate a list of basic and broad, yet essential, bioenergy concepts to be used in the establishment of college-level curricula, similar to curriculum-oriented Delphi studies done by Osborne et al. (2003) for the nature of science and Rossouw et al. (2011) for engineering and technology education. By utilizing the expertise of stakeholders and practitioners in the field, a common language and priorities can be established (Kloser, 2014). The results of this study can be used as a baseline to guide the future development of bioenergy curricula and to develop instruments to measure bioenergy learning in the US, and may be adapted for region-specific technologies in the US and internationally. The themes represent the foundational knowledge students should have in order to begin to contribute effectively to the advancement of this expanding discipline and support them for success in the forthcoming bioeconomy.

**Acknowledgements**

This project is part of the Advanced Hardwood Biofuels Northwest consortium and is supported by Agriculture and Food Research Initiative Competitive Grant No. 2011-68005-30407 from the USDA National Institute of Food and Agriculture. The funding source had no involvement in study design; in the collection, analysis and interpretation of data; in the writing of the report; nor in the decision to submit the article for publication. The authors would also like to thank the panel experts for volunteering their time and knowledge to this study.

**References**

Becker, D. R., Skog, K., Hellman, A., Halvorsen, K. E., & Mace, T. (2009). An outlook for sustainable forest bioenergy production in the Lake States. *Energy Policy*, *37*(12), 5687- 5693.

Communiqué: Making bioeconomy work for sustainable development, Global Bioeconomy Summit, Berlin, Germany, November 2015. Retrieved 5/4/2017 from http://gbs2015.com/fileadmin/gbs2015/Downloads/Communique_final.pdf

Dajani, J. S., Sincoff, M. Z., & Talley, W. K. (1979). Stability and agreement criteria for the termination of Delphi studies. *Technological Forecasting and Social Change*, *13*(1), 83-90.

Dalkey, N., & Helmer, O. (1963). An Experimental Application of the DELPHI Method to the Use of Experts. *Management Science*, *9*(3), 458-467.

Domac, J., Healion, K., Lunnan, A., Madlener, R., Nilsson, S., Richards, K., ... & Segon, V. (2004, January). Educational Work of Iea Bioenergy Task 29: Socio-Economic Drivers in Implementing Bioenergy Projects. In *2nd World Biomass Conference-Biomass for Energy, Industry and Climate Protection* (pp. 10-14).

El-Chichakli, B., von Braun, J., Lang, C., Barben, D., & Philp, J. (2016). Five cornerstones of a global bioeconomy. *Nature, 535*(7611), 221–223.

Engels, T. C., & Kennedy, H. P. (2007). Enhancing a Delphi study on family-focused prevention. *Technological forecasting and social change*, *74*(4), 433-451.

Franklin, K. K., & Hart, J. K. (2007). Idea generation and exploration: benefits and limitations of the policy Delphi research method. *Innovative Higher Education*, *31*(4), 237-246.

Gupta, U.G., & Clark, R.E. (1996). Theory and applications of the Delphi technique: A bibliography (1975-1994). *Technological Forecasting and Social Change*, *58*(3), 185-211.

Hungerford, H., Peyton, R. B., & Wilke, R. J. (1980). Goals for curriculum development in environmental education. *The Journal of Environmental Education*, *11*(3), 42-47.

Kloser, M. (2014). Identifying a core set of science teaching practices: A Delphi expert panel approach. *Journal of Research in Science Teaching*, *51*(9), 1185-1217.

Linstone, H. & Turoff, M. (1975). The Delphi Method: Techniques and Applications. Reading, MA: Addison-Wesley Pub. Co.

Ludwig, B. (1997). Predicting the future: Have you considered using the Delphi methodology. *Journal of Extension*, *35*(5), 1-4.

Malone, K., Harmon, A. H., Dyer, W. E., Maxwell, B. D., & Perillo, C. A. (2014). Development and evaluation of an introductory course in sustainable food and bioenergy systems. *Journal of Agriculture, Food Systems, and Community Development*, *4*, 1-13.

McKenna, H. P. (1994). The Delphi technique: a worthwhile research approach for nursing?. *Journal of Advanced Nursing*, *19*(6), 1221-1225.

Mathews, J. A. (2008). Energizing industrial development. *Transnational Corporations*, *17*(3), 59-84.

McArthur, J. W., & Sachs, J. (2009). Needed: A new generation of problem solvers. *Chronicle of Higher Education*, *55*(40), 1-4.

McCormick, K., & Kautto, N. (2013). The bioeconomy in Europe: An overview. *Sustainability*, *5*(6), 2589-2608.

Murry, J. W., & Hammons, J. O. (1995). Delphi: A versatile methodology for conducting qualitative research. *The Review of Higher Education*, *18*(4), 423.

Okoli, C., & Pawlowski, S. D. (2004). The Delphi method as a research tool: an example, design considerations and applications. *Information & Management*, *42*(1), 15-29.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, *40*(7), 692-720.

Pasztor, J. & Kristoferson, L. (1990). *Bioenergy and the Environment*. Boulder, CO: Westview Press.

Popp, J., Lakner, Z., Harangi-Rákos, M., & Fári, M. (2014). The effect of bioenergy expansion: food, energy, and environment. *Renewable and Sustainable Energy Reviews*, *32*, 559-578.

Quendler, E., & Lamb, M. (2016). Learning as a lifelong process-meeting the challenges of the changing employability landscape: competences, skills and knowledge for sustainable development. *International Journal of Continuing Engineering Education and Life Long Learning, 26*(3), 273-293.

Ransom, C. & Maredia, K. (2012). Building human resources in bioenergy: an international training program at Michigan State University. *Journal of International Agricultural and Extension Education, 19*(2), 10-13.

Rowe, G., & Wright, G. (1996). The impact of task characteristics on the performance of structured group forecasting techniques. *International Journal of Forecasting, 12*(1), 73-89.

Rowe, G., & Wright, G. (1999). The Delphi technique as a forecasting tool: issues and analysis. *International Journal of Forecasting*, *15*(4), 353-375.

Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education*, *21*(4), 409-424.

Sagar, A. D., & Kartha, S. (2007). Bioenergy and sustainable development?. *Annual Review Environ. Resources*, *32*, 131-167.

Scarlat, N., Dallemand, J. F., Monforti-Ferrario, F., & Nita, V. (2015). The role of biomass and bioenergy in a future bioeconomy: policies and facts. *Environmental Development*, *15*, 3-34.

Smáradóttir, S. E. 2014. Future Opportunities for Bioeconomy in the West Nordic Countries. Retrieved 6/1/2015 from http://www.matis.is/media/matis/utgafa/Bioeconomy-in-the-West-Nordic-countries-37-14.pdf.

Suttles, S. A., Tyner, W. E., Shively, G., Sands, R. D., & Sohngen, B. (2014). Economic effects of bioenergy policy in the United States and Europe: A general equilibrium approach focusing on forest biomass. *Renewable Energy*, *69*, 428-436.

Taylor, R., Govindarajalu, C., Levin, J., Meyer, A., & Ward, W. (Eds.). (2008). *Financing energy efficiency: Lessons from Brazil, China*. World Bank: India and Beyond. Washington, D.C.

Toohey, S. (1999). *Designing courses for higher education.* Buckingham: The Society for Research into Higher Education and Open University Press.

Warnmer, S. (2007). *Progress in Biomass and Bioenergy Research.* New York, NY: Nova Science Publishers.

White House. (2012). *National Bioeconomy Blueprint*. Washington, DC, The White House,
April.

White, S., & Walsh, J. (2008). *Greener pathways: Jobs and workforce development in the clean energy economy*. Center on Wisconsin Strategy, Workforce Alliance, Apollo Alliance.

# CHAPTER 3

## Comparing Industry and Academia Priorities in Bioenergy Education: A Delphi Study

Kimi Grzyb[1], Brian D. Hartman[2], and Katharine G. Field[3]
*[1]Environmental Sciences, Oregon State University, [2]Science Education, Walla Walla University, [3]Microbiology, Oregon State University*

### Abstract

Bioenergy is a rapidly growing subsector of the emerging national bioeconomy, with the potential to create a substantial number of jobs. However, programs providing training for these positions are limited, and there is currently a lack of research-based guidance for the creation of new programs. This study employed a modified two-round Delphi technique to generate a prioritized bioenergy education framework, utilizing the expertise of professionals in the field. Participants were presented with a list of bioenergy concepts and asked to use a five-point scale to rate the importance of including each topic in a college-level bioenergy curriculum, and suggestions for additional items were requested. After receiving feedback about the panel's mean ratings from Round One, experts were again asked to rate each item. A comparison between rankings from participants in academia and industry showed that, overall, their priorities are well aligned. The resulting framework will provide structure for developing standardized bioenergy workforce education programs and appropriate evaluation instruments.

**Key Words**: Bioenergy education, bioeconomy, workforce development, curriculum development, standardization

**Introduction**

An increased demand for energy accompanies population growth, resulting in elevated impacts on the environment. The U.S. Energy Information Administration (2013) predicts that between 2010 and 2040, global energy consumption will increase by 56%. This will result in a 46% growth in energy-related carbon dioxide emissions during that same timeframe, based on policies currently in place regarding petroleum use (www.eia.gov). These projections, in conjunction with concerns about national energy security, have prompted increased research and development in the area of bioenergy (e.g. USDA; Warnmer, 2007). Bioenergy, or the solar energy stored in renewable organic matter (biomass), has the potential to provide domestic sources of energy, while also being more sustainable and reliable than traditional fossil fuels (Bauen et al., 2009). Moreover, because biomass resources are dispersed widely across the country, the United States can benefit both financially and environmentally from increased biomass production (Aslan, 2016), particularly in rural communities (Becker, Skog, Hellman, Halvorsen, & Mace, 2009). Bioenergy is also a significant component, and one of the primary industries, of the national bio-based economy (bioeconomy) (Smáradóttir et al., 2014).

The developing bioeconomy is recognized as a way to mitigate climate change while also improving healthcare, manufacturing, agricultural productivity, and energy security in the United States (White House, 2012). It is defined as "the global industrial transition of sustainably utilizing renewable aquatic and terrestrial resources in energy, intermediate, and final products for economic, environmental, social, and national security benefits" (Golden & Handfield, 2014, p.371). The bioeconomy is currently estimated to be responsible for greater than 2% of the US Gross Domestic Product (GDP), although the actual contribution could be 10-20% higher (Carlson, 2016), and is projected to grow (Rosegrant, Ringler, Zhu, Tokgoz, & Bhandary, 2013). Human capital is considered a major bioeconomy resource, while education, sustainability, and innovation comprise the bioeconomy backbone (Smáradóttir et al., 2014).

Industrial biotechnology, which includes bioenergy, is the fastest growing subsector of the national bioeconomy (Carlson, 2016), and this trend is expected to continue both domestically and abroad (Savolainen, Honkanen, & Vertainen, 2013). Moreover, more jobs will be created in bioenergy than other renewable energy options because it is more labor-intensive, and the cost per job created is lower than average petro-chemical employment investments (Domac, Richards, & Risovic, 2005). Many of these employment opportunities will occur in rural areas, which has the added benefit of stimulating economic growth in these areas (Golden & Handfield, 2014). Subsequently, capable employees will be needed to fill these positions, and the lack of a prepared workforce has been identified as a limitation to this growing field (Savolainen, Honkanen, & Vertainen, 2013). In response, bioenergy training programs are being created (Malone, Harmon, Dyer, Maxwell, & Perillo, 2014), and it is anticipated that the next decade will bring about increased education efforts, particularly at the undergraduate level (Klemow, 2015).

Although the National Bioeconomy Blueprint has identified updating training programs as a strategic objective for workforce development in order for the United

States to be competitive in the global economy (White House, 2012), there is currently a lack of research-based guidance and structure for the creation of these programs (Malone et al., 2014). Oftentimes, formation of new curricula occurs when instructors modify readily available resources or courses, resulting in institutional or personal concerns playing a large role in what is ultimately taught to students (Lesieutre, Stewart, & Bridgen, 2013; Linton et al., 2011; Reeves & Jauch, 1978). This type of subjective curriculum creation has become the norm, but research-based curricula can result in higher quality education (Clements, 2007). Additionally, a research-based educational framework can provide a common language to evaluate training programs and measure student learning (Basinger, McKenney, & Auld, 2009). These elements are particularly important in a nascent, yet rapidly growing, educational discipline where the curriculum has not yet been standardized.

When education efforts are directed at workforce development, it is beneficial to involve industry in the curriculum creation process (Gonzalez et al., 2015). One such method, DACUM (Developing a Curriculum), recruits current employees of a specific occupation to identify skills a worker needs to be successful at that job. However, the process can be very time consuming, is most often applicable to a particular locale and position, and is considered more appropriate for occupational training manuals and programs than university education (Bragin et al., 2016). The Delphi technique, on the other hand, provides a platform for more general research-based curriculum development (e.g. Kloser, 2014; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003) and involves the opinions of a variety of stakeholders. The process is also iterative, explicit, and transparent, as recommended by Johnstone and Soares (2014) when developing curricula.

The Delphi technique is employed in forecasting "to obtain the most reliable consensus of opinion of a group of experts…by a series of intensive questionnaires interspersed with controlled feedback" (Dalkey & Helmer, 1963, p.458). It is an iterative, structured group communication process whose value for professional education is in "its capacity to capture those areas of collective knowledge that are held within professions but not often verbalized" (Stewart, 2001, p.922). Over a predetermined number of rounds, experts anonymously generate ideas about a particular topic and rate the importance of those items on a Likert-type scale. The expert panel is then shown the mean ratings, and rerates each item in light of the group's responses, with the goal of building consensus around a subject. The anonymity among panel members, combined with the iterative format, reduces the bandwagon effect, facilitates the expression of honest opinions, and allows participants the freedom to change their minds between rounds without judgment (Rowe & Wright, 1999). The mixed-method characteristics of this technique provide both a quantitative, numerically ranked list of items, as well as rich, explanatory qualitative comments.

Delphi also shares many similarities with the standardization process, or "the process of developing and implementing technical standards" (Goluchowicz & Blind, 2011, p. 1527). For example, both involve heterogeneous participants, a multi-stage coordination process, setting priorities, and aiming for consensus (Goluchowicz & Blind, 2011). Standardization is considered to be necessary for the economic development of a technology and can enhance innovation capabilities (Goluchowicz & Blind, 2011). Blind and Gauch (2009) assert that this process should be implemented as soon as possible, because "Common terminology standards have to be achieved rather early in order to trigger a convergence instead of a divergence in the understanding of the basic elements of a new technology" (p.325). Training based on these standards has the potential to play a critical role in fostering and guiding the transition from an established to a new technology, as in the case of electric vehicles (Brown, Pyke, & Steenhof, 2010). Furthermore, it "can provide assurance to industry professionals of the education potential employees have acquired" (Basinger, McKenney, & Auld, 2009, p.452). It has been argued that the potential for an emerging technology "will be stunted without adequate attention being paid to standards, not only in terms of the speed of its uptake and smoothness of this transition, but also in terms of maintaining compatibility between jurisdictions, safety of the public, and helping to ensure environmental sustainability" (Brown, Pyke, & Steenhof, 2010, p.3797). As more bioenergy training programs are created, standards will be needed to inform their development, as well as assess and evaluate their outcomes (Gregson, 2010), indicating that standardization in the area of bioenergy education is critical at this time.

This study sought to elicit a comprehensive, research-based college-level bioenergy curriculum framework and compare the top priorities of academic and industry experts to investigate whether they are aligned. This comparison allowed insight into the question of whether teachers' main concerns were similar to what potential employers deemed most important for future employees to know. Although seemingly rarely performed in curriculum development, this alignment is a critical piece of training a future workforce (Quendler & Lamb, 2016; Gonzalez et al., 2015). Results of this research can provide guidance for the creation of new bioenergy training programs and begin discussions around standardization in this emerging field.

**Materials and Methods**

A modified two-round Delphi procedure was used for this study to minimize participant fatigue and related attrition (Mullen, 2003). This approach is very similar to a traditional Delphi, except instead of beginning Round One with an open-ended question to prompt the generation of ideas, a modified Delphi begins by presenting the expert panel with a predetermined list of items to be rated. These carefully selected items are most often chosen from an in-depth literature review or by expert solicitation, and additional items may be suggested by the participating panel (Johnston et al., 2013). Due to the emerging nature of this field, and subsequent limited availability of peer-reviewed literature on bioenergy education, the Round One list was produced from the results of a traditional three-round Delphi that initially asked "Keeping in mind the future of a commercial bioenergy industry, what content knowledge should a student have upon completion of a college-level bioenergy curriculum?" (Grzyb, Hartman, Field, in review).

The study was conducted in accordance with the Institutional Review Board regulations at Oregon State University. All correspondence and surveying was done online using Qualtrics (Provo, UT). An invitation to participate included a description of the study, and only the experts that selected "agree" to the online informed consent script were permitted to continue the process. Participants were given approximately two weeks to complete each round, and reminders were sent to encourage continued participation.

***Panel Selection***

The expert panel selection is a critical phase of the Delphi approach, and it has been suggested that the process is only effective if stakeholders who can benefit from the results of the study are involved (Clayton, 1997). For this reason, recruitment efforts aimed for a heterogeneous mix of employers and educators in the bioenergy field from across the country, representing a variety of viewpoints. Panels of experts who have diverse perspectives produce more accurate judgments than experts who are more homogeneous (Lang, 1995; Wallsten, Budescu, Erev, & Diederich, 1997). In order to be considered an "expert" in this study, participants had to meet predetermined requirements (Moore, 1987). For this study, participants were eligible if they had either (a) a publication in a peer-reviewed, bioenergy-related journal; (b) at least two years of experience teaching bioenergy classes at the college level; (c) three years of bioenergy industry experience; and/or (d) a Ph.D in a related field.

Due to the availability of contact information, potential participants were invited if they were: (a) affiliated with one of the eight bioenergy-related United States Department of Agriculture (USDA) Agriculture and Food Research Initiative (AFRI) Community Agriculture Projects (CAP), such as the Advanced Hardwood Biofuels Northwest consortium (www.hardwoodbiofuels.org) and/or (b) employed in a supervisory position at a bioenergy-focused company or government agency.

Recruitment efforts resulted in 57 individuals (42 males, 15 females) who were interested in being a member of the expert panel, 26 (46%) of whom have Ph.Ds. These professionals from industry, government, and academia represented states from across the country, although 25 were from Oregon or Washington. Other states included: Maine, Colorado, California, Wisconsin, New York, New Jersey, Maryland, North Carolina, Hawaii, Georgia, West Virginia, Illinois, and Washington D.C. Representation from the academic sector included professors, instructors, and researchers at universities and community colleges. Areas of academic expertise that were reported included: environmental science, forest management, chemistry, algal biology, entomology, extension education, innovation, natural resource management, and a variety of types of engineering, such as mechanical, chemical, environmental, biological, ecological, and agricultural. Industry representatives included founders, CEOs, presidents, VPs, and marketing directors of bioenergy companies, as well as independent industry consultants. Types of companies included: a corn ethanol plant, the biofuels department of a large aerospace corporation, a purpose-grown woody biomass producer, a carbon capture company that uses gas fermentation to produce biochemicals and biofuels from waste, an anaerobic digestion organization, a non-profit biofuels education organization, and an engineering firm that builds plants to bring concepts to commercialization. Government participants included national directors and advisors from the USDA and U.S. Department of Energy (DOE). Five of the participants were also members of the expert panel in the previous Delphi study (Grzyb, Hartman, & Field, in review) that determined the initial list of bioenergy concepts to be rated in Round One of this study. Participants did not receive any form of monetary incentive and were free to leave the study at any time.

***Round One***

In November 2015, the 57 experts that agreed to participate were sent an initial list of items to be rated on a Likert-type scale from 1 (non-essential) to 5 (essential). They were asked to consider the future of a commercial bioenergy industry as they rated the importance of including each item in a general college-level bioenergy curriculum. These items were: *Energy Basics, Types of Bioenergy, Environmental Impacts (including Life Cycle Analysis), Current Technologies, Societal Issues, Logistics, Policy, Biomass Composition, Non-Bioenergy-Specific Fundamentals, Biomass Production, Conversions, Bioenergy Market, and Business-Related Knowledge.* Descriptive summaries for each concept were also provided (Table 3.1), and the survey software allowed for randomization of the order in which items were presented to each expert (Qualtrics, Provo, UT) to minimize question order bias (Eysenbach, 2004). Experts were invited to add items to the original list and were also encouraged to provide explanations for their ratings, as well as general comments. Aggregate mean scores and standard deviations were calculated, and these items, as well as any additional suggested items, made up the questionnaire for Round Two.

***Round Two***

The final round was initiated in December 2015. During this round, the expert panel was presented with the revised questionnaire, which included two new items suggested from Round One, as well as group mean ratings and standard deviations. In order to encourage consensus, a justification comment was requested if a participant's ratings deviated more than one point from the panel's mean score (e.g. Rossouw, Hacker, & de Vries, 2011). Delphi's iterative format, in addition to allowing participants to change their minds based on the group's responses, also serves as a form of member checking, which confirms that the researchers interpreted replies as intended by participants (Engels & Kennedy, 2007). In response to questions and comments from the expert panel during Round One, the following information was provided to all participants at the beginning of Round Two:

- Due to the interdisciplinary and emerging nature of the field of bioenergy, it is anticipated that students will have a traditional specialization/major (e.g. engineering, agriculture, etc.) in addition to bioenergy education/training.
- Results are intended to inform emerging bioenergy education/training programs to meet the needs of future employers and support students for success in the field of bioenergy.
- The framework is intended to be applicable to all types of bioenergy (technology neutral) and may be adapted for specific technologies.

### *Analysis*

Previous Delphi studies conducted for educational purposes have used analysis of variance to compare the responses of different types of expert panel members (e.g. Kloser, 2014; Osborne et al., 2003). However, because this is a purposefully (non-random) selected group of participants, and the comparison groups are small and different in size (n=26 vs. n=10), this statistical test was not suitable. Instead, because of the non-independence of the study design, we used descriptive statistics to present the results[1] (Quendler & Lamb, 2016).

## Results

### *Round One*

Forty-seven of the 57 experts who initially agreed to participate completed Round One, resulting in an 82.5% response rate.  The Delphi method lacks consensus in the literature regarding cut off scores (Kloser, 2014), so this study used a predetermined mean value of ≥3.6 out of 5 to be included in the following round, as done by Osborne et al. (2003).  This resulted in inclusion of all themes from the original list to be rated in Round Two. Qualitative comments provided by experts led the researchers to add *Bioproducts* and *Ethics* to the Round Two questionnaire; slight modifications were also made to some theme summaries (Table 3.2). The entire panel's mean scores and standard deviations for the original list are shown in Table 3.1.

[1] Most statistical tests require independence between observations, but by design, the Delphi method does not have independent observations.  At the first round, the participants' responses can be considered independent, as they (presumably) are not influencing each other.  However, at the next round, participants see the mean rating and standard deviation for each theme before rating each theme again.  There is even a greater possibility of statistical dependence since they are asked to justify their rating if it deviates too far from the mean.

Table 3.1

*Entire Panel's Rating Results for Round One*

| Theme Title/Summary | Round One | |
|---|---|---|
| | *M*[1] | *SD* |
| Energy Basics: Students should understand the fundamental principles of energy | 4.43 | 0.81 |
| Environmental Impacts (including Life Cycle Analysis): Students should be familiar with positive and negative environmental impacts related to bioenergy production and evaluate inputs and outputs to make informed decisions | 4.30 | 0.92 |
| Policy: Students should be familiar with existing and proposed policies that influence the growth of the industry | 4.23 | 0.83 |
| Types of Bioenergy: Students should be familiar with a broad range of available and emerging types of bioenergy | 4.17 | 0.95 |
| Current Technologies: Students should be familiar with current energy production | 4.13 | 0.72 |
| Non-Bioenergy-Specific Fundamentals: Students should have fundamental coursework and skills (Biology, Chemistry, Math, Physics, Writing Skills, Ecosystems, Communication, Data Analysis/Statistics, Process Modeling) | 4.13 | 1.02 |
| Societal Issues: Students should recognize the societal consequences (pros and cons) resulting from a bioenergy industry | 4.00 | 0.92 |
| Logistics: Students should understand the planning, implementation, and coordination required for the bioenergy supply-chain | 3.89 | 0.90 |
| Biomass Composition: Students should know the basic biomass components | 3.87 | 1.05 |
| Biomass Production: Students should understand the methods involved with producing commercial quantities of biomass | 3.85 | 1.03 |
| Bioenergy Market: Students should be familiar with the current and projected bioenergy market | 3.83 | 0.90 |
| Conversions: Students should have scientific knowledge of converting biomass to intermediates and end products | 3.83 | 1.04 |
| Business-Related Knowledge: Students should have a basic understanding of business management and strategy (Finance, Economics, Risk/SWOT Analysis, Return on Investment Calculations) | 3.78 | 1.05 |

[1]Means on a 5-point scale of 1 "not essential" to 5 "essential"; SD=Standard Deviation.

***Round Two***

Of the 47 experts who participated in Round One, 41 (87%) responded to the Round Two questionnaire. Upon completion of Round Two, eight of the 15 themes had a mean of ≥4 on the five-point scale (Table 3.2), signifying that the experts considered them important, and all but one (*Ethics*) had standard deviations of <1.0, which indicates a high level of consensus (Osborne et al., 2003) for these themes. An expert comment prompted the decision by the researchers that *Ethics* would be more appropriately categorized as a sub-theme of *Non-Bioenergy-Specific Fundamentals.*

Table 3.2.

*Entire Panel's Rating Results from Round Two, with Additional and Modified Items Presented to Experts in Round Two*

| Theme Title/Summary | Round Two $M^1$ | Round Two $SD$ |
|---|---|---|
| Energy Basics: Students should understand the fundamental principles of energy | 4.67 | 0.53 |
| Types of Bioenergy: Students should be familiar with a broad range of available and emerging types of bioenergy | 4.59 | 0.50 |
| *Environmental Impacts (including Life Cycle Analysis): Students should be familiar with positive and negative environmental impacts related to bioenergy production and sustainability, and evaluate inputs and outputs to make informed decisions | 4.49 | 0.60 |
| *Non-Bioenergy-Specific Fundamentals: In addition to bioenergy-specific topics, students should also have fundamental coursework and skills (e.g. biology, chemistry, engineering, writing skills, data analysis, statistics) | 4.28 | 0.72 |
| *Current Technologies: Students should be familiar with current energy production, including fossil fuel and renewable energy technologies, and how they compare to bioenergy options. | 4.21 | 0.61 |
| *Societal Issues: Students should recognize the societal consequences (pros and cons) resulting from a bioenergy industry, as well as the concerns associated with consumer acceptance and landowner/producers' willingness to supply biomass | 4.13 | 0.80 |
| **Bioproducts: Students should recognize the value of co-products in improving the overall economics and potential of bioenergy | 4.05 | 0.83 |
| *Biomass Production: Students should understand the methods involved with producing commercial quantities of biomass, including production costs and yields | 4.00 | 0.73 |
| *Policy: Students should be familiar with existing and proposed policies that influence the growth of the industry, including Renewable Identification Numbers (RINs) and certification processes | 3.87 | 0.66 |
| Logistics: Students should understand the planning, implementation, and coordination required for the bioenergy supply-chain | 3.72 | 0.76 |
| *Biomass Composition: Students should know the basic biomass components and recognize that the chemical composition of biomass impacts the quality of biomass products | 3.64 | 0.78 |
| **Ethics: Students should be aware of the moral principles involved to conduct themselves and guide technological development in an ethical manner | 3.64 | 1.06 |
| Bioenergy Market: Students should be familiar with the current and projected bioenergy market | 3.59 | 0.68 |
| Conversions: Students should have scientific knowledge of converting biomass to intermediates and end products | 3.51 | 0.76 |
| Business-Related Knowledge: Students should have a basic understanding of business management and strategy (Finance, Economics, Risk/SWOT Analysis, Return on Investment Calculations) | 3.36 | 0.74 |

**new or *modified items; [1]Means on a 5-point scale of 1 "not essential" to 5 "essential"; SD=standard deviation.

***Comparison between Academia and Industry Priorities***

In order to gain insight about whether the priorities of educators and employers were aligned, the means for each of those groups were calculated for comparison (Table 3.3) (Quendler & Lamb, 2016).

Table 3.3

*Comparison of Industry and Academia Priorities after Round Two*

| | Industry N=10 | | | Academia N=26 | | |
|---|---|---|---|---|---|---|
| Theme Title/Summary | *M*[1] | *SD* | *Rank* | *M*[1] | *SD* | *Rank* |
| Types of Bioenergy | 4.60 | 0.52 | 1 | 4.58 | 0.50 | 2 |
| Energy Basics | 4.50 | 0.71 | 2 | 4.77 | 0.43 | 1 |
| Non-Bioenergy-Specific Fundamentals | 4.40 | 0.70 | 3 | 4.19 | 0.75 | 5 |
| Environmental Impacts (including Life Cycle Analysis) | 4.20 | 0.63 | 4 | 4.58 | 0.58 | 2 |
| Current Technologies | 4.10 | 0.74 | 5 | 4.27 | 0.60 | 3 |
| Biomass Production | 4.10 | 0.74 | 5 | 3.96 | 0.72 | 7 |
| Bioproducts | 4.10 | 0.77 | 5 | 4.00 | 0.85 | 6 |
| Societal Issues | 3.80 | 0.79 | 6 | 4.23 | 0.82 | 4 |
| Policy | 3.70 | 0.48 | 7 | 3.88 | 0.71 | 8 |
| Logistics | 3.70 | 0.67 | 7 | 3.65 | 0.80 | 9 |
| Bioenergy Market | 3.60 | 0.52 | 8 | 3.54 | 0.50 | 11 |
| Biomass Composition | 3.60 | 0.84 | 8 | 3.62 | 0.75 | 10 |
| Business-Related Knowledge | 3.40 | 0.97 | 9 | 3.27 | 0.60 | 12 |
| Ethics | 3.50 | 1.27 | 10 | 3.65 | 1.02 | 9 |
| Conversions | 3.30 | 0.95 | 11 | 3.54 | 0.71 | 11 |

[1]Means on a 5-point scale of 1 “not essential” to 5 “essential.” SD=standard deviation, N=number of experts.

Figure 3.1 presents the top five priorities of academia and industry and illustrates that their main concerns are aligned. There were multiple ties for rankings, so more than five items are displayed. Energy Basics, Types of Bioenergy, Environmental Impacts, Current Technologies, and Non-Bioenergy-Specific Fundamentals were shared top priorities. The theme Societal Issues was also considered a top priority for academia, while Bioproducts and Biomass Production were ranked in the top five for industry.

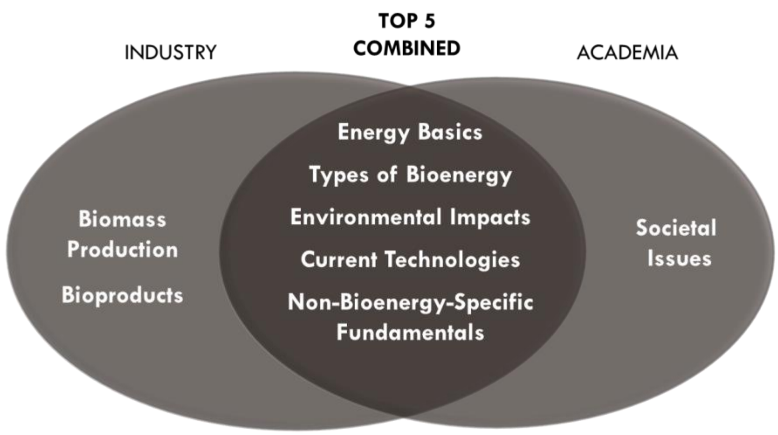


*Figure 3.1.* Depiction of aligned priorities. The dark shape represents where top priorities are aligned. Lighter gray shapes show additional top five priorities for industry and academia. There are more than five items due to tied ranking scores.
Source: Author's own.

Qualitative comments provided some insight regarding the differences in opinions between academics and industry professionals regarding Societal Issues. Industry felt that a technology needed to be economically feasible before warranting concerns about Societal Issues, while academics sensed that in order to be economically feasible, the technology would first need to be accepted by society. For example, industry expert quotes included the following:

- "Societal issues [are] secondary to other issues with biomass. Not to discount societal issues; but if you cannot make things work from economical, logistical, policy, or critical mass perspective; there is not reason to get into essential understanding of societal implications" (Industry expert).
- "I can appreciate the groups wanting the students to understand society's feelings but this just doesn't rank very high for me. I think if it makes economic sense it will be done. Social aspect is great, but doesn't drive economic decisions (be it right or wrong)" (Industry expert).

Experts from academia, on the other hand, had the following to say about *Societal Issues*:

- "The main motivation behind the promotion of bioenergy is to achieve wider societal goods such as climate change mitigation, energy security improvement, and rural development; in most cases bioenergy has no advantage over fossil alternatives outside of these effects. Any curriculum that glosses over these completely misses the point!" (Academic expert).
- "People are important! Decisions by society are part of what will make or break this industry" (Academic expert).
- "All the environmental and economic viability in the world won't help without having it be socially acceptable" (Academic expert).

*Bioproducts* was ranked fifth by industry and sixth by academia with a mere 0.1 point difference in the mean ratings (4.10 vs. 4.00). In a previous study conducted in early 2014 (Grzyb, Field, & Hartman, in review), *Bioproducts* was not revealed as its own theme, but, rather, included as "intermediate and end products" under the theme of

"*Conversions"*. This could be explained by the fact that oil was much more expensive at that time, making biofuels more economically competitive. Additionally, biochemicals have overshadowed fuels in terms of revenues and are now the largest component of the industrial biotech sector, and are estimated to generate ~0.4% of the US GDP (Carlson, 2016).

The expert panel shared similar sentiments about the importance of bioproducts:

- "It is very important to enhance or maximize the value of the biomass and reduce the productivity [production] costs." (Industry expert)
- "[V]ery important in a world with $34/barrel oil. You need to make bioenergy a high value proposition and co products are a key way to do this." (Industry expert)
- "Good petrochemical refineries make 80% of their profit on 20% of their output. That 20% [is] higher margin co-products." (Industry expert)
- "Absolute necessity. Without co product production and marketing the effort will not cash flow or provide required return to investor." (Government expert)
- "…the production of bio-based jet fuel will only be financially feasible if high-value co-products are produced as well." (Academia expert)
- "With the new bioeconomy and biochemicals this is a very important topic to teach!" (Academia expert)

Unfortunately, there were less informative comments about *Biomass Production* from academia experts. However, there were two comments from industry experts that indicated this theme was rated higher by industry, again, because of its relevancy to potential financial gains: "If they don't know the cost of production they cannot make a profit, or know the constraints of feedstock delivery/production" (Industry expert), and "Students need to understand the full economic potential and drawbacks of different types of biomass" (Industry expert). It is notable that *Societal Issues* ranked sixth for industry experts, while *Bioproducts* and *Biomass Production* ranked sixth and seventh, respectively, for academia experts (Table 3.4).

Table 3.4

*Final Recommended College-level Bioenergy Curriculum Framework*

| Theme Title/Summary |
|---|
| Energy Basics: Students should understand the fundamental principles of energy. |
| *Types of Bioenergy: Students should be familiar with a broad range of available and emerging types of bioenergy, including the differences among first, second, and third generation biofuels. |
| *Environmental Impacts (including Life Cycle Analysis): Students should be familiar with positive and negative environmental impacts related to bioenergy production and sustainability, and evaluate inputs and outputs to make informed decisions. |
| *Non-Bioenergy-Specific Fundamentals: In addition to bioenergy-specific topics, students should also have fundamental coursework and skills (e.g. biology, chemistry, engineering, writing skills, data analysis, statistics, communication skills, ethics). |
| *Current Technologies: Students should be familiar with current energy production, including fossil fuel and renewable energy technologies, and how they compare to bioenergy options. |
| *Societal Issues: Students should recognize the societal consequences (pros and cons) resulting from a bioenergy industry, as well as the concerns associated with consumer acceptance. |
| Bioproducts: Students should recognize the value of co-products in improving the overall economics and potential of bioenergy. |
| *Biomass Production: Students should understand the methods involved with producing commercial quantities of biomass, including production costs and yields, as well as advantages of certain types of feedstocks over others. |

Table 3.4 (Continued)

*Policy: Students should be familiar with existing and proposed policies that influence the growth of the industry, including Renewable Identification Numbers (RINs), certification processes, and carbon trading.

Logistics: Students should understand the planning, implementation, and coordination required for the bioenergy supply-chain.

Biomass Composition: Students should know the basic biomass components and recognize that the chemical composition of biomass impacts the quality of biomass products.

Bioenergy Market: Students should be familiar with the current and projected bioenergy market.

Conversions: Students should have general knowledge of converting biomass to intermediates and end products.

Business-Related Knowledge: Students should have a basic understanding of business management and strategy (Finance, Economics, Risk/SWOT Analysis, Return on Investment Calculations).

*****modified items

Oftentimes, cut off scores are implemented in order to make a list of items more manageable and meaningful. However, because the final list was relatively short, the researchers chose to include all items in the final framework (Table 3.4). Table 3.4 also displays changes in summary wording to reflect qualitative comments from the experts.

***Open-ended Comments***

The term “bioenergy” encompasses a vast array of technologies, from biofuels such as corn and cellulosic ethanol to microbial fuel cells. For this reason, this study aimed to distill components of the varied technologies down to the themes that were common to “bioenergy”, while remaining technology neutral. There was agreement among many members of the expert panel that the importance of each of the items will be different for different types of occupations and specific skills needed for each. One expert gave the advice to "Stick with a broadly accessible core accessible to all, and add special details for advanced courses". Another expert elaborated on this idea by stating,

> They are all important but some more than others depending on what the desired output of the student will be. For instance, if we expect the students to be technical experts on how to make various types of bioenergy, then the technical topics become 'must-haves' while the other business and societal issues have lesser importance (but still a role). Likewise, if we expect to product [sic] students to be leaders on the business side of bioenergy, then the technical topics have lesser importance (but still have a role) and the societal, business and policy topics become 'must haves'.

In a similar sentiment, another expert expressed that

> I think that bioenergy courses are great vehicles to learn/review energy basics, and to talk about societal issues (climate change, rural development, energy security, etc.) as it relates to energy use in general. Beyond that, I think the most important topics for students to understand are that a) there are a range of bioenergy technology types at or approaching commercial maturity, b) estimation of environmental impacts/benefits is complex, and c) scale up of bioenergy in particular is heavily dependent on supportive policy measures. I think all other topics are somewhat secondary; to the extent that they pique student interest that's great, but the finer details are not absolutely necessary to understand the broader importance and potential role of bioenergy in climate change mitigation.

These comments suggest that the themes comprising this curriculum framework may be designated as the "Core Domains" (Johnston et al., 2013) of a holistic bioenergy training program. These core domains can provide a way to organize the more detailed competencies that are needed for specific occupations related to a specific technology. Competencies are defined as "a set of knowledge, skills, and abilities required to successfully perform tasks in a defined work setting" (Johnston et al., 2013, p.14). For example, one of the government experts listed highly desirable traits for an employee in the bioenergy field, but depending on the employment position, some of these skills may be unnecessary. However, this comment does provide some examples of more detailed competencies that could be required of a competent employee:

> Planning to include feasibility studies, business plans, technical reports, financial modeling and budgeting, resource assessments, per design surveys, design & engineering requirements, permits/agreements, contracts, warrantees and performance guarantees. Implementation to include qualification of project team, scheduling, procurement, operations, maintenance, training, installation, testing, commissioning, and startup to full production. Coordination through project management through protocols, communication, tracking systems, and monitoring with documentation.

**Discussion**

The global bioeconomy is growing, and its vibrancy is dependent on the education and skills of its workers (White House, 2012). Energy from biomass, which makes up a large part of the bioeconomy, increased 60% between 2006-2013, and accounts for approximately half of all renewable energy use in the United States (EIA, 2013). However, other countries and their companies are also striving to be leaders in this area (Obama, 2017) because biomass energy consumption positively affects short- and long-term economic growth (Aslan, 2016). Therefore, the United States should advance bioenergy education resources, because it will “prepare the next generation to compete successfully in a bio-economy” (White House, 2012, p.34).

Building and maintaining a more capable and better trained workforce may offer the most sustainable competitive advantage for an organization (Huselid & Becker, 2011). However, in order to generate this valuable human capital in an emerging field, new training programs and resources, such as the framework described in this paper, are needed. If designed well, individuals, teams, organizations, and society as a whole can benefit from these training programs (Salas, Tannenbaum, Kraiger, & Smith-Jentsch, 2012; Aguinis & Kraiger, 2009). Jennings (2009) asserts that education plays a particularly critical role in developing a renewable energy industry, specifically, because education: promotes greater public awareness of a technology; develops consumer confidence in the technology; creates engineers, scientists, and researchers who develop new systems, devices, and technologies for the industry; assists in training technicians that design install, and maintain high quality renewable energy systems; provides information for policy analysts who are able to produce effective policies for the industry; and trains workers who can advise and assist future customers of the technology. Therefore, it is particularly advantageous to create effective, research-based, standardized training programs in this emerging field.

Many of the skills and specific competencies described by experts would be common to multiple job positions, but clearly, for example, a policy analyst working in the cellulosic ethanol field would require significantly different competencies than an agronomist working to reduce pests or improve irrigation for growing biomass. For this reason, the framework is intended to be all-inclusive of the many bioenergy technologies and related jobs. Although there are some fairly specific items included in the framework (e.g. RINs), they were incorporated because they are specific to bioenergy and should be discussed at a general level to make students aware of their existence, even if they won't personally work directly with RINs in their future position.

The field of bioenergy is a dynamic one, and the results of this study represent the opinions of this panel of American experts in 2015. As more innovations reach commercial status, as oil prices fluctuate, and as policies and incentives for bioenergy progress, opinions change (McKenna, 1994). By comparing these results with a similar, previously conducted study (Grzyb, Hartman, & Field, in review), the emergence of the new theme *Bioproducts* exemplifies how the field of bioenergy has evolved in just a few years. It also illustrates the need for standardization, because "[a] standard set of terms to describe skills/attributes would enhance the comparability of research results as well as permit the identification and analysis of changes over time" (Tanyel, Mitchell, & McAlum, 1999, p.37). Moreover, creating standards by involving both academia and industry is beneficial, because it assures companies that students have been trained appropriately, and it gives students confidence that they are learning what companies want them to know in order to be hired (Obama, 2011). Additionally, other items that are present in the literature that were not revealed through this study include the use of municipal solid waste (MSW) as a feedstock (e.g. Gaeta-Bernardi & Parente, 2016), food security (e.g. El-Chichakli, von Braun, Lang, Barben, & Philp, 2016), and Bioenergy with Carbon Capture and Sequestration (BECCS) (e.g. Muratori, Calvin, Wise, Kyle, & Edmonds, 2016). Importance of these items varies among regions and countries depending on implemented policies, technological and economic feasibility, and available markets. These additional examples of how the field has progressed, and likely others not mentioned here, reiterate the need for continuous research to keep training programs relevant and up-to-date.

Recently, El-Chichakli, von Braun, Lang, Barben, and Philp (2016) indicated international collaboration among educators as one of the five cornerstones of the global bioeconomy. They emphasize the importance of defining the knowledge, skills and competencies required for developing the bioeconomy to enrich the sustainable use and manufacturing of bio-based materials. Moreover, they specifically state that "This will require an interdisciplinary approach that emphasizes systems thinking, strategic planning and evaluating environmental, social and economic performance, as well as an understanding of technologies and local specifics" (p. 223), all of which is touched upon in this framework, but future research efforts should include international panel members.

By utilizing the expertise of professionals in industry, academia, and government, it was possible to collate the ideas of these stakeholders to create a comprehensive curriculum framework. It is promising that the results indicate that the priorities of academia and industry are well aligned, signifying that students are being taught what employers consider important for future employees to know. Gonzalez et al. (2015) recommend creating strong and lasting partnerships with industry when designing energy curricula to increase its value, because employers are critical for identifying job requirements, as well as vacancies that need to be filled. This framework can provide a systematic basis for updating training in a field that will be continually evolving, and it is intended to be flexible so that it may be adapted and updated for particular technologies and/or job positions. Research-based curricula studies, such as the one described here, can improve standardization among bioenergy training programs, poising the United States to maintain a competitive edge for success in the global bioeconomy through workforce development.

**Acknowledgements**

This project is part of the Advanced Hardwood Biofuels Northwest consortium and was supported by Agriculture and Food Research Initiative Competitive Grant No. 2011-68005-30407 from the USDA National Institute of Food and Agriculture. The funding source had no involvement in study design; in the collection, analysis and interpretation of data; in the writing of the report; nor in the decision to submit the article for publication.

**References**

Aguinis, H., & Kraiger, K. (2009). Benefits of training and development for individuals and teams, organizations, and society. *Annual Review of Psychology*, *60*, 451-474.

Aslan, A. (2016). The causal relationship between biomass energy use and economic growth in the United States. *Renewable and Sustainable Energy Reviews*, *57*, 362-366.

Baker, J., Lovell, K., & Harris, N. (2006). How expert are the experts? An exploration of the concept of 'expert' within Delphi panel techniques. *Nurse Researcher*, *14*(1), 59-70.

Basinger, A. R., McKenney, C. B., & Auld, D. (2009). Competencies for a United States horticulture undergraduate major: A national Delphi study. *HortTechnology*, *19*(2), 452-458.

Bauen, A., Berndes, G., Junginger, M., Londo, H. M., Vuille, F., Ball, R., ... & Mozaffarian, M. (2016). Bioenergy: A sustainable and reliable energy source. *Policy Studies*, *20*, 21-25.

Becker, D. R., Skog, K., Hellman, A., Halvorsen, K. E., & Mace, T. (2009). An outlook for sustainable forest bioenergy production in the Lake States. *Energy Policy*, *37*(12), 5687-5693.

Blind, K., & Gauch, S. (2009). Research and standardisation in nanotechnology: Evidence from Germany. *The Journal of Technology Transfer*, *34*(3), 320-342.

Bragin, M., Tosone, C., Ihrig, E., Mollere, V., Niazi, A., & Mayel, E. (2016). Building culturally relevant social work for children in the midst of armed conflict: Applying the DACUM method in Afghanistan. *International Social Work*, *59*(6), 745-749.

Brown, S., Pyke, D., & Steenhof, P. (2010). Electric vehicles: The role and importance of standards in an emerging market. *Energy Policy*, *38*(7), 3797-3806.

Carlson, R. (2016). Estimating the biotech sector's contribution to the US economy. *Nature Biotechnology*, *34*(3), 247-255.

Clayton, M. J. (1997). Delphi: A technique to harness expert opinion for critical decision-making tasks in education. *Educational Psychology*, *17*(4), 373-386.

Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. *Management Science*, *9*(3), 458-467.

Domac, J., Richards, K., & Risovic, S. (2005). Socio-economic drivers in implementing bioenergy projects. *Biomass and Bioenergy*, *28*(2), 97-106.

El-Chichakli, B., von Braun, J., Lang, C., Barben, D., & Philp, J. (2016). Five cornerstones of a global bioeconomy. *Nature*, *535*(7611), 221–223.

Engels, T. C., & Kennedy, H. P. (2007). Enhancing a Delphi study on family-focused prevention. T*echnological Forecasting and Social Change*, *74*(4), 433-451.

Eysenbach, G. (2004). Improving the quality of Web surveys: the checklist for reporting results of internet e-surveys (CHERRIES). *Journal of Med. Internet Research*, *6*(3), 34.

Gaeta-Bernardi, A., & Parente, V. (2016). Organic municipal solid waste (MSW) as feedstock for biodiesel production: A financial feasibility analysis. *Renewable Energy, 86*, 1422-1432.

Glaser, V. (2013). Meeting current needs and assessing future opportunities to drive the global bioeconomy. *Industrial Biotechnology*, *9*(5), 271-274.

Golden, J. S., & Handfield, R. B. (2014). Why biobased? Opportunities in the emerging bioeconomy. *US Department of Agriculture, Office of Procurement and Property Management, Washington, DC, USA.* Retrieved from http://www. biopreferred. gov/files/WhyBiobased. pdf.

Goluchowicz, K., & Blind, K. (2011). Identification of future fields of standardisation: An explorative application of the Delphi methodology. *Technological Forecasting and Social Change*, *78*(9), 1526-1541.

Gonzalez, G. C., Singh, R., Karam, R., Ortiz, D. S., Robson, S., Phillips, A., & Hunter, G. (2015). Aligning Education and Training to Meet Energy Workforce Needs. Santa Monica, CA: RAND Corporation. http://www.rand.org/pubs/research_briefs/RB9810.html.

Gregson, J. (2010). A conceptual framework for green career and technical education: Sustainability and the development of a green-collar workforce. *Journal of Technical Education and Training*, *2*(1), 123-137.

Grzyb, K., Hartman, B.D., & Field, K.G. (in review). Determining essential components of a college-level bioenergy curriculum using the Delphi technique.

Huselid, M.A., & Becker, B.E. (2011). Bridging micro and micro domains: Workforce differentiation and strategic human resource management. *Journal of Management*, *37*(2), *421-428.*

Johnston, L. M., Wiedmann, M., Orta-Ramirez, A., Oliver, H. F., Nightingale, K. K., Moore, C. M., & Jaykus, L. A. (2014). Identification of core competencies for an undergraduate food safety curriculum using a modified Delphi approach. *Journal of Food Science Education*, *13*(1), 12-21.

Johnstone, S. M., & Soares, L. (2014). Principles for developing competency-based education programs. *Change: The Magazine of Higher Learning*, *46*(2), 12-19.

Klemow, K. (2015). Undergraduate energy education: The interdisciplinary imperative. *Journal of Sustainability Education,8*.

Retrieved from http://www.jsedimensions.org/wordpress/content/undergraduate-energy-education-the-interdisciplinary-imperative_2015_01/.

Kloser, M. (2014). Identifying a core set of science teaching practices: A Delphi expert panel approach. *Journal of Research in Science Teaching*, *51*(9), 1185-1217.

Lang, P. J. (1995). The emotion probe: Studies of motivation and attention. *American Psychologist*, *50*(5), 372.

Linton, R., Nutsch, A., McSwane, D., Kastner, J., Bhatt, T., Hodge, S., ... & Woodley, C. (2011). Use of a stakeholder-driven DACUM process to define knowledge areas for food protection and defense. *Journal of Homeland Security and Emergency Management*, *8*(2), 6.

Lesieutre, G. A., Stewart, S. W., & Bridgen, M. (2013). *Wind energy workforce development: Engineering, science, & technology*. University Park, PA: The Pennsylvania State University Press.

Malone, K., Harmon, A. H., Dyer, W. E., Maxwell, B. D., & Perillo, C. A. (2014). Development and evaluation of an introductory course in sustainable food and bioenergy systems. *Journal of Agriculture, Food Systems, and Community Development*, *4*, 1-13.

Moore, C.M. (1987). *Group techniques for idea building.* California: Sage.

Mullen, P. M. (2003). Delphi: Myths and reality. *Journal of Health Organization and Management*, *17*(1), 37-52.

Muratori, M., Calvin, K., Wise, M., Kyle, P., & Edmonds, J. (2016). Global economic consequences of deploying bioenergy with carbon capture and storage (BECCS). *Environmental Research Letters*, *11*(9), 95-104.

Obama, B. "Remarks by the President at Closing Session of Winning the Future Forum on Small Business in Cleveland, Ohio". Office of the Press Secretary, 22 February 2011, Cleveland State University, OH. Speech. Retrieved from https://www.whitehouse.gov/the-press-office/2011/02/22/remarks-president-closing-session-winning-future-forum-small-business-cl.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, *40*(7), 692-720.

Quendler, E., & Lamb, M. (2016). Learning as a lifelong process-meeting the challenges of the changing employability landscape: competences, skills and knowledge for sustainable development. *International Journal of Continuing Engineering Education and Life Long Learning*, *26*(3), 273-293.

Reeves, G., & Jauch, L. R. (1978). Curriculum development through Delphi. *Research in Higher Education*, *8*(2), 157-168.

Rosegrant, M. W., Ringler, C., Zhu, T., Tokgoz, S., & Bhandary, P. (2013). Water and food in the bioeconomy: Challenges and opportunities for development. *Agricultural Economics*, *44*(1), 139-150.

Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education*, *21*(4), 409-424.

Rowe, G., & Wright, G. (1999). The Delphi technique as a forecasting tool: issues and analysis. *International Journal of Forecasting*, *15*(4), 353-375.

Salas, E., Tannenbaum, S. I., Kraiger, K., & Smith-Jentsch, K. A. (2012). The science of training and development in organizations: What matters in practice. *Psychological Science in the Public Interest*, *13*(2), 74-101.

Savolainen, V., Honkanen, H., & Vertainen, L. (2013, September). *Bioenergy education and industry & commerce hand in hand–challenges and practical solutions*. Paper presented at Bioenergy 2013 Exhibition and Conference, (pp.49-53) Jyväskylä, Finland.  Retrieved from https://www.researchgate.net/profile/Saad_Butt3/publication/260936415_Using_catalysts_to_reduce_the_emissions_from_a_new_biomass_small_scale_combustion_unit/links/551453450cf283ee08353176.pdf#page=51.

Smáradóttir, S. E. (2014). *Future opportunities for bioeconomy in the West Nordic countries.* Retrieved 6/1/2015 from http://www.matis.is/media/matis/utgafa/Bioeconomy-in-the-West-Nordic-countries-37-14.pdf.

Stewart, J. (2001). Is the Delphi technique a qualitative method? *Medical Education*, *35*(10), 922-923.

Tanyel, F., Mitchell, M. A., & McAlum, H. G. (1999). The skill set for success of new business school graduates: Do prospective employers and university faculty agree? *Journal of Education for Business*, *75*(1), 33-37.

United States Department of Agriculture. (2011). Agriculture Secretary Vilsack announces major investments to spur innovation and job creation in research, development and production of next generation biofuels [Press Release]. Retrieved from http://www.usda.gov/wps/portal/usda/usdamediafb?contentid=2011/09/0425.xml&printable=true&contentidonly=true.

United States Energy Information Administration. (2013). Retrieved 12/1/2016 from www.eia.gov.

Wallsten, T. S., Budescu, D. V., Erev, I., & Diederich, A. (1997). Evaluating and combining subjective probability estimates. *Journal of Behavioral Decision Making*, *10*(3), 243-268.

Warnmer, S. (2007). *Progress in biomass and bioenergy research.* New York, NY: Nova Science Publishers.

White House. (2012). *National Bioeconomy Blueprint*. Washington, DC, The White House, April.

# CHAPTER 4

## An Interdisciplinary, Research-based Minor in Bioenergy

Kimi Grzyb[1], Zhenglun Li[2], and Katharine G. Field[3, 4]
Oregon State University, Corvallis, Oregon, USA
[1]*Environmental Sciences*, [2]*BioResource Research*, [3]*Microbiology*

**Abstract**

The interdisciplinary, research-based bioenergy minor at Oregon State University (OSU) invites students from any major to become involved in the growing field of bioenergy. This unique 29-35 credit minor includes three required core courses, three related electives in technology, environment, and society/economics/policy, as well as a ten-credit research experience, three credits of thesis/scientific writing, and one credit each of data presentation and seminar. Through exposure to expert guest lecturers, field trips, lab tours, group projects, proposal writing, and research and presentation opportunities, this minor prepares students for a broad array of careers and graduate programs in the bioenergy field. The minor requirements, minor-specific courses, and student feedback are described, to support the establishment of similar programs at other universities. We present the minor as it was first offered in 2013 and discuss ways in which the program has evolved based on research findings and feedback from current students and alumni.

**Key words**: bioenergy education, bioeconomy, sustainability, innovation, service learning

**Introduction**

The energy stored in biomass could provide an important and sustainable solution to help mitigate climate change and contribute to energy security (Creutzig et al., 2015). However, in order for a commercial bioenergy industry to be successful, a variety of employees will need to be trained to be effective along the entire supply chain, from growing crops to marketing fuels and other bioproducts. Currently, courses and curricula dedicated to bioenergy are lacking in the United States (Ransom and Maredia, 2012). For these reasons, there is a growing need for interdisciplinary education that prepares students to think innovatively and holistically to solve complex problems (McArthur and Sachs, 2009). To address this need for a well-educated renewable energy sector workforce, Oregon State University (OSU) now offers an undergraduate minor degree in bioenergy. Initiated with funding from the United States Department of Agriculture (USDA), this minor program was developed as part of the educational component of the Advanced Hardwood Biofuels Northwest consortium (www.Hardwoodbiofuels.org).

The purpose of this paper is to provide a detailed description of this pioneering undergraduate minor in bioenergy, to provide guidance for the creation of similar courses and/or degree programs at other institutions. We describe the design of the minor, as it was initially offered in 2013, discuss findings from a student survey and alumni interviews, and comment on how the program has evolved based on research findings and student feedback.

**Program Description**

The OSU Bioenergy Minor combines comprehensive course content with direct exposure to industry and research, in order to produce graduates who are prepared to enter this growing field. The minor was designed using a successful OSU research-based major as a model (http://agsci.oregonstate.edu/bioresource-research/bioresource-research). Requirements include core courses, electives in the areas of technology, environment, and society/economics/policy, and an authentic undergraduate research experience (URE), including writing a thesis and presenting results in a public seminar (Table 4.1).

Table 4.1

*OSU Bioenergy Minor Requirements*

| | **Course Number** | **# Credits** |
|---|---|---|
| **First-year Core** | | |
| Introduction to Regional Bioenergy | BRR 250 | 2 |
| Interdisciplinary Research – Bioenergy Focus | BRR 350 | 2 |
| Bioenergy and Environmental Impact | WSE 473 | 3 |
| **Electives:** one course from each of 3 categories | | |
| Technical | | 2-4 |
| Environmental | | 2-4 |
| Social/Economic/Policy | | 2-4 |
| **Research** with a mentor | BRR 401 | 10 |
| **Thesis** (students receive formal instruction) | BRR 403 | 3 |
| **Science Communication** (formal instruction) | BRR 406 | 1 |
| **Public Seminar** (formal instruction) | BRR 407 | 1 |

Source: Authors' own.

### ***Bioenergy-specific Courses***

Two courses, both offered through the BioResource Research (BRR) program at OSU, were created specifically for the bioenergy minor. OSU adheres to a 10-week quarter system, as opposed to semesters. Intended to be taken in sequence (though not required), the fall term course provides an overview of bioenergy from a variety of perspectives, while the winter term course focuses on the research process and specific bioenergy-related projects happening at OSU. Neither of these courses has prerequisites and both have been deliberately designed to support the success of students from any discipline. When recruiting students from a variety of majors, it can be difficult to schedule a class time, so both classes are held once a week in the evening from 6-750pm when most other classes are over, to reduce conflicts. The third required core course, offered spring term, is a preexisting Wood Science Engineering class (WSE 473) entitled *Bioenergy and Environmental Impacts*, and will not be elaborated on in this paper.

#### *Introduction to Regional Bioenergy (BRR 250)*

Offered for the first time in fall 2013, this two-credit course introduces bioenergy core concepts and issues and relates them to regional bioenergy businesses and facilities through guest lectures, field trips and group projects. Specifically, it is intended that after taking this course, students will be able to: demonstrate an understanding of the core concepts of bioenergy, including feedstocks, conversion, and life cycle impacts; present and discuss important contemporary issues relating to bioenergy; effectively communicate bioenergy concepts; and explore and evaluate the role of bioenergy in regional industry. To ensure students are provided with the most up-to-date and accurate information, professors and industry professionals were brought in to deliver lectures in their fields of expertise. Examples of these lecture topics and presenters are detailed in Table 4.2. To increase accessibility, this course was also developed into an eCampus online course, and the recorded lectures were made available on an open-access YouTube channel (https://www.youtube.com/channel/UCiFXuor4e2agZo5aApgVpTQ).

Table 4.2

*BRR250 Bioenergy Topics and Lecturers*

| **Lecture Title** | **Example topics** | **Presenter** |
|---|---|---|
| Introduction to Bioenergy | · Bioenergy history and context<br>· Carbon sources: petroleum vs. biomass<br>· Basic chemistry<br>· Conversions: Thermal, chemical, biological, and mechanical<br>· Barriers to current bioenergy success | Senior Process Chemist, Biofuels Company |
| Feedstocks and Conversion | · Biomass composition: cellulose, hemicellulose, lignin<br>· Examples of feedstocks<br>· Basic chemistry: sugar vs. starch<br>· Pretreatment<br>· Enzymes | Professor, OSU Food Science and Technology Department |
| Life Cycle Analysis (LCA) and Sustainability | · 1st, 2nd, 3rd generation biofuels<br>· Social, environmental, economic sustainability<br>· Use of resources in processing (e.g. water, energy)<br>· LCA start/end points (i.e. cradle to grave, gate, or cradle)<br>· Consequential vs. Attributional LCA<br>· LCA modeling and software options | Professor, OSU Department of Biological and Ecological Engineering |
| Bioenergy Policy and Regulations | · Role of policy<br>· Energy as a marketable public good<br>· Energy security<br>· Lack of national carbon tax<br>· Federal vs. regional policy<br>· Incentives and mandates<br>· Case studies where policy had unintended outcomes<br>· Energy Policy Act of 2005 and Energy Independence and Security Act (EISA), 2007 | Professor, OSU Political Science Department |
| Business of Bioenergy | · Entrepreneurship<br>· Risk analysis | Mixed panel of entrepreneurs and industry professionals |

Source: Authors’ own.

Students are also required to attend two field trips to local bioenergy facilities to witness first-hand how the topics covered during lectures are applied in ‘real life’. During the years this course has been offered, tours have included, for example, a waste water treatment plant, a biodiesel refinery, a biogas facility, a poplar tree farm, a methane-producing landfill, a biochar plant, and a microbial fuel cell research laboratory.

*Interdisciplinary Research – Bioenergy Focus (BRR 350)*

Ideally, students take BRR 250 first to gain general bioenergy knowledge, followed by BRR 350, which exposes them to current bioenergy research projects, as well as the general research process, to prepare them for their own 10-credit research experience. After completing BRR 350, students are expected to be able to: evaluate research talks and papers, explain the scientific issues addressed, discuss ethical considerations, and assess conclusions; explain the research process, including quantitative and qualitative research methods and the use of evidence; describe key components of a research proposal; effectively use the library and writing resources available on campus; and suggest interdisciplinary approaches to solving bioenergy problems. Guest speakers are invited to present their research, and topics have included, for example: creation of sterile poplar trees using molecular techniques, torrefaction of forest residues using concentrated solar heat, policy and regulations related to renewable fuels in the state of Oregon, increasing efficiency of biomass transportation, and diatoms as biofuel factories. Other assignments include searching databases and citing references, presenting a bioenergy-related current event, identifying a need or knowledge gap and writing an appropriate research proposal addressing that need, and analyzing peer-reviewed journal articles related to the technical, social, and economic aspects of bioenergy.

*Interdisciplinary Aspects*: Interdisciplinarity is a synthesis of two or more disciplines that establishes a new level of discourse and integration of knowledge (Klein, 1990). Interdisciplinary thinking is defined as the ‘capacity to integrate knowledge of two or more disciplines to produce a cognitive advancement in ways that would have been impossible or unlikely through single disciplinary means’ (Spelt et al., 2009, p.365). To highlight the interdisciplinary nature of the field of bioenergy, after each lecture, students break into multidisciplinary teams for a group discussion. Students are asked to pose a question about the lecture content from the viewpoint of their major field and discuss potential interdisciplinary approaches to a solution with their group. Because the bioenergy minor is open to all majors, students have come from a variety of departments and majors, including, for example: agriculture, biochemistry and biophysics, bioengineering, botany and plant pathology, business management, chemical engineering, chemistry, ecological engineering, environmental science, horticulture, microbiology, political science, renewable materials, and sociology. Not only is the program interdisciplinary in terms of student make-up, but it is also interdisciplinary in the topics covered and the guest speakers and instructors who contribute to the courses. Additionally, the variety of options available to fulfill the elective requirements provides students with the opportunity to enroll in courses they otherwise may not take.

***Other Required Courses***

*Research (BRR 401)*

A unique and valuable element of the bioenergy minor is the required 10-credit authentic research experience. Students work with an advisor to discuss their research interests and identify an appropriate research project and mentor. A variety of empirical studies have investigated the benefits students gain through an undergraduate research experience, which is defined as ‘an inquiry or investigation conducted by an undergraduate that makes an original intellectual or creative contribution to the discipline’ (Hu et al., 2008, p. 6).

A successful undergraduate research experience results in many gains for the student, such as increased self-efficacy, thinking like a scientist, exposure to cutting-edge technology, clarification of and enhanced preparation for career and/or graduate school goals, and a variety of other ‘soft’ skills such as time management, organization, communication, and ability to work both independently and as part of a team (e.g. Seymour et al., 2004; Guterman, 2007). In addition to the ‘real-world’ exposure to innovative research and content knowledge, these ‘soft skills’ (e.g. Robles, 2012) gained through UREs add to the well-roundedness of the graduates of this program. Similarly, it has been shown that problem solving can be enhanced by collaborating with others who are more knowledgeable in the field (Vygotsky, 1978), which, in this case, often includes the research mentor, postdocs, graduate students, and other undergraduates.

Each student has both a primary and secondary mentor who are selected based on the student’s interests; mentors must hold PhDs. With help from the BRR academic advisor, students identify prospective mentors in academia and industry (on or off campus), send in a resume, and set up a meeting to discuss potential research projects. Once a match has been made, students meet with their mentors and the BRR Director to discuss expectations and milestones. It is expected that for each research credit they are registered for, students will spend three to five hours each week doing research-related work. Student research projects thus far have included a broad variety of topics, including algal biofuels, biochar, biodiesel, education, enzymes, innovative products from lignin, microbial fuel cells, molecular genetics of feedstock crops, policy, biomass pretreatment, and rural community development.

*Thesis (BRR 403)*

Upon completion of the research experience and required courses, bioenergy minor students are required to write a thesis, allowing them to develop writing skills that will be essential to their professional careers. To support this endeavor, a required three-credit course, taught by the BRR director, is offered every term and meets once a week. After taking this course, students are expected to be able to competently convey the meaning of research results in written and oral format, and demonstrate the ability to communicate with both professionals and the general public. Course activities include peer review of classmates' theses drafts. The thesis is expected to be written in the format of a manuscript submitted to a scientific journal, and is typically 20 double-spaced pages of text, plus tables, figures, references, and appendices. All theses become a permanent part of the OSU Library Scholars Archive (http://ir.library.oregonstate.edu/xmlui/handle/1957/456/discover), and some are ultimately published.

*Data Presentation (BRR 406)*

The purpose of this 1-credit course is for students who are doing research to learn to develop and evaluate poster and slide presentations containing scientific data. During this course, students create scientific posters, improve them based on peer feedback, and present them at a formal poster session. In addition to the poster, students are also required to prepare and present an eight to ten-minute mini research seminar to practice oral presentation skills. Presentations include a two-to five-minute question and answer session, and presenters are critiqued by fellow classmates on organization, delivery, visual aids, and knowledge of subject matter, using an evaluation rubric.

*Seminar (BRR 407)*

In preparation for their final seminar, this course provides the opportunity to produce and practice a 35 to 40-minute seminar. Students receive critiques from other students to improve their presentations and to prepare them to answer potential questions from the audience regarding methods, instrumentation, specific organisms, statistics, limitations, and possible next steps in their research. This course enables students to demonstrate their capabilities and understanding of the entire research process by clearly communicating their project to others.

## Program Evaluation

### *Materials and Methods*

In order to assess the OSU Bioenergy Minor from the students' perspective, a survey (Appendix H) was designed to allow current students and graduates to provide responses to open-ended questions regarding program strengths and weaknesses, the interdisciplinary nature of the program, and skills gained through research experiences. We also solicited supplementary comments on topics that were not specifically addressed in the survey. Content analysis (Tesch, 1990) of the data was used to generate categories by two members of the research team; groupings were then discussed until 100% inter-rater reliability was reached.

Open-ended responses provided valuable information for program developers and course instructors. Because students' research projects and mentors differ substantially, as well as their choice of electives, there was often a broad spectrum of responses to the prompts. For this reason, responses were coded into broader categories, and only the most salient themes for each question, along with example quotes, are reported. Additional learning-outcomes-based items were included on the survey for the purpose of program evaluation conducted by an external evaluator and will not be discussed in this paper.

### ***Results***

#### *Student Surveys*

Of the 50 current and former students in the program who were invited to take the survey, 31 (62%) agreed to the consent form and began the survey. There was no incentive for participation in the survey, but students were reminded via email and also by some instructors of the core bioenergy courses. All responses were recorded between June 2013 and April 2016. Because participation was voluntary, students were able to skip individual questions, occasionally resulting in an incomplete data set. For analysis to determine gains through pre- and post- responses, incomplete questionnaires were discarded. However, because coding of the open-ended questions and analysis of demographic items do not require pre- and post- responses, all of these responses were included in the analysis.

*Participant Demographics*

Students that participated in the survey graduated or anticipate graduating with a minor in bioenergy from OSU between December 2016 and June 2019, and 97% had completed or were currently enrolled in courses specific to the bioenergy minor. Most (n=28, 93%) had taken BRR 250 (described above), 28 (93%) had taken BRR 350 (described above), 17 (15%) had taken the third core bioenergy course, WSE 473, and the percentage of those who had completed or were enrolled in at least one type of elective at the time the survey was administered was as follows: Technical = 68%, Environmental = 44%, and Social/Economic/Policy = 54%. The majority of survey participants (n=14, 45%) had Senior class standing, followed by 5$^{th}$ year Seniors (n=8, 26%), Juniors (n=7, 23%), and Sophomores (n=2, 7%). Males represented the majority (62%) of the respondents. Of the 27 participants who responded to questions about ethnicity, age, and first-generation college student status, 74% (n=20) are White, 15% (n=4) are Asian, one is Hispanic or Latino, one is Black, and one preferred not to answer; 63% (n=17) were 22 years of age or younger; and 37% (n=10) are first generation college students. When asked about their plans post-graduation, 42% planned to enter the workforce, and 42% planned to apply to graduate school. Five others were either undecided, or hoped to start their own business or volunteer with the US Peace Corps.

*Program Strengths*

When asked to describe three strengths of the bioenergy minor program, the most frequently mentioned topic was the research experience, followed by scholarship funding, interdisciplinary nature and quality of faculty (tied), flexibility and networking opportunities (tied), and sustainable problem-solving (Table 4.3).

Table 4.3.

*OSU Bioenergy Minor Program Strengths*

| Survey Item | Response Category | # Responses |
|---|---|---|
| 'Describe 3 strengths of the bioenergy minor program' | Research experience | 15 |
| | Scholarship funding | 11 |
| | Interdisciplinary nature | 9 |
| | Quality of faculty | 9 |
| | Flexibility | 8 |
| | Networking opportunities | 8 |

Source: Authors' own.

*Research experience:* Regarding the research project, students felt that they gained practical experience that they wouldn't have been exposed to solely through coursework. Skills gained during their projects prepared them for the job market and graduate school, while also providing a competitive edge for future careers, because writing a thesis would help them stand out from other undergraduates who had not written a thesis. One student claimed that it was 'vital to my success' because that student hoped to attend graduate school and believed the research experience would be highly valued by admissions committees, because it 'promote[d] deeper thinking about the bioenergy field' and resulted in an 'increased confidence level in the ability to communicate complex ideas…and vast implications of…bioenergy'. Students also appreciated the authenticity of participating in 'real research with faculty, as opposed to contrived research representations, which, after countless hours of undergraduate coursework, gets old very quickly.'

*Scholarship funding:* Initial grant funding through AHB provided substantial scholarship funding for many students. This was considered a strength of the program because not only did it provide incentive for joining the program, it also made participation feasible for students who would otherwise have to work a part-time job instead of participating in the research experience. Additionally, adding a minor is, by nature, more costly to the students, and the funding helped alleviate some of these added costs.

*Interdisciplinary nature:* The interdisciplinary nature of the program was valued because students recognized that solving energy production issues is not a single-faceted task and that interdisciplinary collaboration and communication is 'critical' to succeed. Students also appreciated the variety of students from diverse majors 'which allows for good dialogue regarding tough topics', 'allows for multidisciplinary projects,' and presents a 'broad spectrum of fields and people to network with.'

*Quality of faculty:* Because of the infancy of the program, it is smaller and more intimate than some traditional minors, which allows students to work more closely with program staff. Faculty were described as 'friendly,' 'available,' 'professional,' 'talented,' and 'passionate,' and students appreciated the 'individualized assistance' and 'one on one time' provided by advisors and instructors.

*Flexibility:* The flexibility of the program was highlighted because it could be adapted to complement the academic requirements of the students' major departments, and the 'extensive' list of electives allowed students to cater to their personal interests and 'learn about the areas we [the students] feel are most important'.

*Networking opportunities:* Students also felt the many networking opportunities delivered through field trips, guest lectures, and working with mentors were beneficial. This exposure to professionals in the field provided 'industry connections' and was referred to as 'a gateway to many other opportunities' such as internships, new bioenergy topics, and research projects. Networking also gave students a better idea of the variety of careers relevant to bioenergy. One student elaborated on this by saying 'There are tons of field trip opportunities and guest speakers that help give some idea to the job market of bioenergy after graduation [and] get you excited about what bioenergy and the work that we are doing means to the future.'

*Areas Needing Improvement*

Responses to the prompt 'Describe three areas needing improvement' revealed that students would like more course options, including electives, clearly defined instructions for their individual research project, and more marketing of the program (Table 4.4). Six students responded that they did not have suggestions for improvement; two of these specified that was due to being a new student with limited knowledge of the program.

Table 4.4

*OSU Bioenergy Minor Program Areas Needing Improvement*

| Survey Item | Response Category | # Responses |
|---|---|---|
| 'Describe three areas needing improvement' | Courses (difficulty/electives) | 11 |
| | Research project expectations | 8 |
| | Marketing of program | 7 |
| | Outreach opportunities | 6 |

Source: Authors' own.

*Courses:* There were a number of comments about the core courses, as well as the elective choices. Multiple respondents mentioned that BRR 250 was 'a very easy introductory course' and 'could be made more difficult', whereas BRR 350 'was quite challenging', and WSE 473 'could be expanded on and increased to two terms'. One student wanted more chemistry, while another wanted 'courses on energy systems that are not just for engineers.' There were also comments requesting 'elective opportunities that are more inclusive and comprehensive for non-physical science majors' because prerequisites inhibited students from taking electives that interested them. Another student suggested that more courses be cross-listed with other departments associated with bioenergy, such as microbiology, 'for enhancing and improving knowledge of specific bioenergy disciplines'.

*Research project expectations:* Multiple comments indicated that finding and completing the research experience requires a substantial amount of work and time, particularly when compared to other minors. Students stated that they would appreciate more detailed information about how to find an appropriate research project and mentor, as well as 'guidelines' and 'clearer timeline of research milestones.'

*Marketing of program:* A number of survey participants expressed that the program should be advertised more because it is 'relatively small':

'I've spoken with many people who are very disappointed that they didn't know of the program earlier';

'Better awareness of the program';

'Marketing of this minor as it's not very well known yet';

'Promoting the program needs to be done on campus or off. I feel like no one really knows about it';

'It is not very well publicized'.

*Outreach opportunities:* Statements that fell under this theme suggested that students would appreciate the opportunity to participate in outreach as an 'extracurricular learning activity'. Outreach specifically provides students with opportunities to communicate scientific information to a lay audience (Saab, 2010). One student stated the desire for 'functions or presentations which [sic] help to bring awareness of the issues and needs to the community not just those working in the field to reach common bioenergy goals'. Another suggested 'more interaction with the OSU community…We are doing something great and should show it…'

*Gains from Research Experience*

Only students who had identified and started their research projects were asked about the skills and knowledge they had gained by participating in undergraduate research, resulting in 17 responses. Students were welcome to list as many items as they wanted; some were project-specific techniques, while others were broader personal gains (Table 4.5).

Table 4.5.

*Student Gains from Research Experience*

| Survey Item | Response Category | # Responses |
|---|---|---|
| 'What skills and knowledge have you gained by participating in undergraduate research?' | Designing a research project | 7 |
| | Collecting and analyzing data | 7 |
| | Soft Skills (e.g. communication, time management) | 7 |

Source: Authors' own.

*Designing a research project:* Students benefited by learning to design experiments with 'proper controls' to answer specific research questions and 'test hypothes[e]s'. One student claimed, 'I've also learned more about how to design a research experiment that would give a more precise answer than before.' Participating in a research project allowed students to 'translate knowledge learned in the classroom into real laboratory techniques' and gain a 'much better understanding of the research process and real-world application of science'.

*Collecting and analyzing data:* The majority of students who answered this question specifically mentioned working with and interpreting data. Some students gave specific examples such as 'soil sample analyses', 'extraction', 'cell culturing and counting', or 'making dilutions.' Others mentioned exposure to and familiarity with a variety of instruments and tools such as 'microscope', 'autoclave', 'centrifuge', 'lab notebook', and 'Matlab and Comsol modeling software'.

*Soft skills:* In addition to technical skills, students also mentioned a variety of soft skills they gained 'to bring to the workforce'. These included working independently, time management, 'patience', 'enhanced critical thinking', thinking 'with a more analytical mindset than previously', scientific writing, improved oral presentation skills, and communicating results to 'people of many levels of education' from children to 'accomplished and experienced' professionals.

*Benefits of Interdisciplinary Nature*

Students were presented with the following prompt after all of the open-ended questions, in order to prevent this question from suggesting responses for the other questions: 'The Bioenergy Minor Program at Oregon State University was purposefully designed to be interdisciplinary, offering flexibility, access from a variety of fields, and utility, particularly with respect to the choice of electives. Please comment on what you feel are the benefits of the interdisciplinary nature of the minor program.' Students found the interdisciplinary nature of the program to be beneficial because it supported interaction with a variety of viewpoints, demonstrated the need for interdisciplinary collaboration to solve complex problems, and allowed students to customize their course selection based on personal interests and passions (Table 4.6).

Table 4.6

*Benefits of Interdisciplinary Nature of the OSU Bioenergy Minor Program*

| **Survey Item** | **Response Category** | **# Responses** |
|---|---|---|
| 'Please comment on what you feel are the benefits of the interdisciplinary nature of the minor program' | Working with diverse students and different perspectives | 14 |
| | Representative of 'real world' problems | 7 |
| | Customizable based on interests | 7 |

Source: Authors' own.

*Working with diverse students and different perspectives:* One student encompassed this theme in a single quote: 'It allows students to interact with people they wouldn't normally work with. Taking classes and discussing research with people from a variety of fields and backgrounds gives students a broader perspective on the issues we study.' Others found the interdisciplinary nature beneficial because of the 'high degree of potential to cultivate cross-disciplinary relationships', because they 'gain a better understanding of how multiple approaches to problems can be effective,' and because it 'allows students to really consider the many facets of the challenges and opportunities that bioenergy industry presents'. In addition, 'it opens up the field for even more ideas to be shared between students and staff creating an even larger pool to draw from and add to for resources, information, and creativity.'

*Representative of 'real world' problems:* Seven students commented that the interdisciplinary nature was representative of real world problems; two quotes captured the overall feel of this theme:

'Possessing useful knowledge and skills from multiple academic areas is crucial to being able to converse and work with others to find solutions to real world problems'; and

> Complex problems (such as climate change and meeting energy demands) require a multidisciplinary approach. There are many components to these problems (technology, economics, policy, education, etc.) and one person is not likely to be an expert at all of them. It is important for the bioenergy minor program to be an interdisciplinary program in order to better prepare students for solving real world problems.

*Customizable based on interests:* Because it is interdisciplinary, students can choose both the research project and electives based on personal preference, which 'allows for students to focus on aspects that they enjoy or that they personally think are important.' It also enables students to be exposed to multiple topics to help students figure out what they are most passionate about, as in the case of this student:

> When I took the intro to bioenergy course I was excited by all the types of processes and didn't know if I wanted to study everything from biochar, coproducts, pretreatment, and feedstock physiology/genetics. Because of being able to choose my courses I could incorporate a few of my interests to strengthen my research and focus.

*Interviews*

In order to gain specific insight about the impact of the program on alumni, semi-structured interviews were conducted over the phone and in person with four recent graduates of the program. These students were asked to comment about what they considered the most beneficial part of the program, what they gained from their research experience, whether they thought the interdisciplinary nature of bioenergy was well represented, and any suggestions for improvement. These interviews were digitally recorded, transcribed, and analyzed for salient themes. In line with the survey results, the alumni all mentioned that the research component was a highly valuable aspect of the program. According to the students, 'the experience of working with the research advisor in a big lab group and learning things from other students in that lab group, that was a really good experience and good exposure to what doing research is really like', and 'I think it makes me stand out a little bit when people are looking at my resume....it gives me more of a leg up than somebody who didn't do research, especially with an emerging topic'. It was also considered a strength because of the lab skills they acquired, such as microscopy, gas chromatography, and colorimetric assays, and for one student, 'by doing a research project you learn to stay organized, sample labeling, storage, and my cell [culture] skills exponentially increased out of necessity…being more lab savvy helps me be more efficient with my time.' Subsequently, because they were required to write a thesis about their research, writing skills also improved, and they gained familiarity with manuscript formatting and technical writing. The coursework was also considered beneficial because it 'provided a greater insight into the current industry and its workings, where the bioenergy industry is currently and how it's developing'. Overall, it was agreed that the interdisciplinary aspect was exemplified, both in the subjects that were taught, and in the diverse interests and backgrounds of the students in the class. Suggestions for improvement included recruiting more students, improving the process of finding a research mentor, and adding 'some sort of culminating, maybe group, project where…you put an interdisciplinary team together and overcome some challenge.' These students were also welcome to add any additional comments, and from these remarks it was evident that they also very much appreciated the financial support they received as scholarships and research funds.

## Discussion

### *Evolution of the Program*

The field of bioenergy is a dynamic one, which requires that continual changes be made to training programs so that they remain current and effective. Based on formative program assessment, student feedback, changing oil prices, and advances in bioenergy education research, the OSU Bioenergy Minor has evolved in a variety of ways since its inception, including some substantial and impactful modifications to the program.

Survey results revealed that students would like more course options, including electives, as well as more outreach opportunities outside of class. In response to these requests, and in line with supporting a national bioeconomy, a new version of the minor is under development. The newly proposed 'Bioinnovations' minor will offer a research track that is very similar to the original bioenergy minor, but there will also be an innovation track option. Through collaboration with the OSU College of Business, students will add more business, entrepreneurship, and management courses. A service learning component will connect the minor students with opportunities to engage in outreach and educate pre-college students about bioenergy, which supports learning through teaching (Warren, 2012) and addresses the students' desire for more outreach opportunities, as determined from the survey results (Table 4.4). Business courses will teach project management and marketing skills for bringing bioinnovations to market. These added course options will add to the interdisciplinarity of the program and may improve students' interdisciplinary thinking.

The required scientific research component of the bioenergy minor is highly beneficial and pertinent for science and engineering students, but an equally valuable culminating experience was needed for students in the social sciences and business who choose the innovation track. In the new track, students will participate in a capstone project in lieu of the research project. The new five-credit capstone course will focus on the development of new innovative bioenergy co-products. Students will identify and evaluate new co-products, select the co-product that is most market ready, and build a business plan. This course will also incorporate the elements of public presentation that the research track students currently gain through presenting a public seminar.

With the emergence of fracking and unstable oil prices, the economic feasibility of biofuels requires that other high-value products, such as lubricants and adhesives, be co-generated for profit. In fact, bioproducts have surpassed biofuels in terms of revenue (Carlson, 2016). Additionally, a Delphi consensus study (Grzyb et al., in preparation) that identified pertinent components of a college-level bioenergy curriculum indicated bioproducts as a priority topic. For these reasons, and to support the bioeconomy, BRR 250 ‘Introduction to Bioenergy’ will be updated to ‘Introduction to Bioenergy and the Bioeconomy’ and will include bioproducts lectures and a field trip to a bioproducts facility.

Because the bioenergy minor is open to all majors, students come from diverse backgrounds, and subsequently, there is a vast range of research projects and associated mentors. Survey comments suggested that the expectations and milestones for the research experience should be more clearly defined to provide consistency among experiences. Projects will continue to vary based on student interests, but in order to standardize the process, a detailed syllabus for the research project has been created to keep students on track for project completion. A significant requirement for these credits is to maintain a lab notebook/journal to record accomplishments and protocols, problems encountered, date and number of hours worked, and lab or field results. Other assignments include: attending lab meetings or other regularly scheduled meetings with a supervisor; writing a research proposal using primary literature that must be approved by the faculty mentor; producing an appropriate list of electives to be taken, also initialed by the mentor; creating figures and tables to communicate research data; and developing a time line for completion as part of a progress report that is discussed with the mentor, secondary mentor, and program director. Research projects differ in length and students start them at various times during their undergraduate career, so these assignments are done term-by-term and provide guidance for students to attain milestones in a timely manner.

Additionally, perhaps because it is a relatively new minor, enrollment has been below capacity. Survey comments also indicated that marketing for the program should be improved. To address the need for increased advertising for the program, a communications specialist was hired in 2014. This person utilizes social media, press releases, direct contact with academic advisors, and professionally designed flyers to increase awareness of the program. These efforts have resulted in an increase from seven students enrolled the first year, to 30 at the time this article was written, and up to 100 students involved in the component courses.

**Conclusion**

A prosperous bioenergy industry will demand a well-trained workforce capable of cross-disciplinary innovation and problem-solving. To address this need, a first of its kind minor was established. This interdisciplinary educational model, with a culminating experience in the form of a research project or capstone business course, provides a well-rounded education to students who graduate with a variety of soft skills and technical competencies that can be transferred to other emerging industries.

The minor has provided students with tangible exposure to interdisciplinary content, and students in the program appreciate the interdisciplinarity. Extensive elective options enable students to pursue their personal interests and leverage their strengths. This has resulted in the program's demonstrated ability to engage a diverse audience.

Student feedback has been very informative and has resulted in alterations being made to the program. By offering two separate tracks to completion of the bioenergy minor, accessibility, particularly by students outside of STEM majors, could be improved. However, as noted by the students, as well as Watkinson, Bridgwater and Luxmore (2012), pioneering bioenergy programs must be promoted extensively to increase awareness in order to attract talented students.

This program is the first of its kind in the United States, and the only bioenergy minor currently available that requires a research component, but new programs are emerging (Malone, 2013). Although content must be updated regularly to remain current, as in the case of adding bioproducts, this educational model may be useful for other institutions implementing new educational programs in bioenergy.

**Acknowledgments**

This project is part of the Advanced Hardwood Biofuels Northwest consortium and was supported by Agriculture and Food Research Initiative Competitive Grant No. 2011-68005-30407 from the USDA National Institute of Food and Agriculture.

**References**

Carlson, R. (2016). Estimating the biotech sector's contribution to the US economy. *Nature Biotechnology*, *34*(3), 247-255.

Creutzig, F., Ravindranath, N. H., Berndes, G., Bolwig, S., Bright, R., Cherubini, F., & Fargione, J. (2015). Bioenergy and climate change mitigation: an assessment. *GCB Bioenergy*, 7(5), 916-944.

*Grzyb, K., Hartman*, B.D., & Field, K.G. (in preparation). Comparing industry and academia priorities in bioenergy education: A Delphi study.

Guterman, L. (2007). What good is undergraduate research, anyway? *Chronicle of Higher Education*, *53*(50), 11.

Hu, S., Scheuch, K., Schwartz, R. A., Gayles, J. G., & Li, S. (2008). *Reinventing undergraduate education: Engaging college students in research and creative activities*. San Francisco, CA: Jossey-Bass.

Klein, J. T. (1990). *Interdisciplinarity: History, theory, and practice*. Detroit, MI: Wayne State University Press.

Malone, K., Harmon, A. H., Dyer, W. E., Maxwell, B. D., & Perillo, C. A. (2014). Development and evaluation of an introductory course in sustainable food and bioenergy systems. *Journal of Agriculture, Food Systems, and Community Development*, 4, 1-13.

McArthur, J. W., & Sachs, J. (2009). Needed: A new generation of problem solvers. *Chronicle of Higher Education*, *55*(40), 1–4.

Ransom, C., Maredia, K. (2012). Building human resources in bioenergy: an international training program at Michigan State University. *Journal of International Agricultural and Extension Education*, *19*(2), 10–13.

Robles, M. M. (2012). Executive perceptions of the top 10 soft skills needed in today’s workplace. *Business Communication Quarterly*, *75*(4), 453-465.

Saab, B. (2010). Engaging the clutch of the science communication continuum – Shifting science outreach into high gear. *Hypothesis*, 9(1), 12.

Seymour, E., Hunter, A. B., Laursen, S. L., & DeAntoni, T. (2004). Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. *Science Education*, *88*(4), 493-534.

Spelt, E. J., Biemans, H. J., Tobi, H., Luning, P. A., & Mulder, M. (2009). Teaching and learning in interdisciplinary higher education: A systematic review. *Educational Psychology Review*, *21*(4), 365.

Tesch, R. (1990). *Qualitative analysis: Analysis types and software tools*. London: Falmer.

Vygotsky, L. (1978). *Mind in Society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Warren, J. L. (2012). Does service-learning increase student learning? A meta-analysis. *Michigan Journal of Community Service Learning*, *18*(2), 56-61.

Watkinson, I. I., Bridgwater, A. V., & Luxmore, C. (2012). Advanced education and training in bioenergy in Europe. *Biomass and Bioenergy*, *38*, 128-143.

# CHAPTER 5

## Discussion

This chapter synthesizes findings from the Delphi studies and incorporates student feedback about the OSU interdisciplinary bioenergy minor to illustrate the contributions and implications of these combined studies. The reasons for conducting a separate case study to collect student opinions, instead of simply including students in the Delphi panel were: 1) in order to ensure that the industry and academia opinions were from "experts", we developed a rigorous, predetermined set of expert qualifications that could not be met by undergraduate students, and 2) the separate study allowed the acquisition of in-depth, first-hand accounts from current students and recent alumni that participated in the minor that was described in detail, versus merely asking their opinion of important bioenergy topics to be learned at the undergraduate level. Moreover, due to the lack of bioenergy-explicit training programs, it likely would have been difficult to find a sufficient number of heterogeneous, geographically dispersed students to participate. In this chapter, recommendations for bioenergy training programs and how these recommendations align with existing programs and previous research findings are presented. In conclusion, a proposed educational model to develop T-shaped bioenergy employees is presented.

As noted by the National Academy of Sciences and the National Academy of Engineering (National Academies, 2007), sustainable approaches to concerns about energy, the environment, and agriculture are prominent in the grand challenges of the 21$^{st}$ Century. In order to contend with these problems, a move towards a global bioeconomy has begun, and establishing a successful bioenergy industry is one of the key strategies that will advance this effort. To accomplish this, a properly trained and capable workforce will be required; therefore, strong and effective educational programs in this field must be established. To address this need, it is necessary to consult with the main stakeholders involved in this process, specifically industry employers, educators, and students. Not only can education prepare future workers to innovate to solve complex problems, but it also results in a knowledgeable citizenry that will make appropriate, sustainable decisions as consumers by improving awareness and confidence in new technologies (Domac et al, 2004; Zografakis, Menegaki &Tsagarakis, 2008). Moreover, instilling interest in the bioenergy field can motivate students to pursue sustainability careers in STEM fields (Malone et al., 2014).

The resulting set of recommendations, based on the synthesis of expert opinion and student feedback, share many of the qualities deemed important by other countries and programs. Due to the gap in the literature regarding bioenergy-explicit education, comparators have been extrapolated to sustainable development and renewable energy programs, as well as general interdisciplinary education characteristics. For example, findings from both the Delphi studies and case study echo the claims of Hopkins and McKeown (2002) that suggest students need to have knowledge in both the natural and social sciences in order to understand sustainable development and its implications.

The following three examples of relevant existing bioenergy education programs exemplify some of the common characteristics chosen by curricula developers for effective learning, including interdisciplinarity and experiential learning components, and their implications:

- At the University of Maryland Eastern Shore (UMES), the National Bioenergy and Bioproducts Educational Programs (NBBEP, a partnership among six universities) ran a week-long summer institute for Science, Technology, Engineering, Agriculture, and Mathematics (STEAM) teachers and faculty (Mitra, Nagchaudhuri, Rutzke, 2013). The goals of this interdisciplinary, experiential learning experience were to: 1) generate better appreciation for bioenergy and bio-based products and their implications on climate change and the environment, foreign policies, and rural, regional, and national economies; 2) refine middle school, high school, and undergraduate education by incorporating more bioenergy materials into the STEAM curricula; 3) motivate and inspire students to pursue STEAM and sustainability careers; and 4) strengthen collaborations among researchers and educators through internships/summer field experience. The "systems-perspective" activities included a field trip to a local biodiesel company, making biodiesel from various oils and soap from the glycerin produced through that process, determining sugar content from a variety of feedstocks with different pre-treatment applications, and designing photobioreactors for culturing algae. Surveys revealed that participants gained content knowledge and also expressed plans to incorporate the hands-on activities into existing curricula (Mitra, Nagchaudhuri, Rutzke, 2013).
- An interdisciplinary undergraduate degree program, Sustainable Food and Bioenergy Systems (SFBS), was implemented at Montana State University in response to the growing need for innovative, trained professionals that are able to solve problems in the food, agriculture, and bioenergy industries (Malone et al.,

2014). To address production, utilization, and distribution of food and bioenergy, SFBS created a new course that combines classroom and field instruction. According to the authors, “course themes, goals, and topics were chosen with considerable input from SBFS faculty…additionally, several food, agriculture and energy stakeholders were surveyed for recommendations” (p.2). This “systems thinking” approach included multidisciplinary teaching and experiential learning to introduce students to bioenergy topics, expose them to career opportunities, promote networking between students and SFBS stakeholders, and provide first-hand experience through projects and field trips. Some of the topics covered were agro-ecology, soil and plant sciences, pest management, climate change, and public policy. Pre-post surveys provided evidence that the course was effective in causing positive changes in students' career and academic goals, as well as lifestyle choices, such as choosing locally grown food. Additionally, 40% of students who took the course expressed that bioenergy was the most interesting topic that was covered in the course (Malone et al., 2014). Clearly there is interest among students in the topic of bioenergy, but although stakeholders were involved in the curriculum design, this process was not research-based or transparent, as advocated by Clements (2007).

- In 2009, a Bioenergy Feedstock Production course was created as a required course for engineering undergraduates pursuing a bioenergy minor (Thelen, Gao, Hoben, Qian, Saffron, & Withers, 2012). Lectures, group projects, and demonstrations covered topics such as cultivation, harvesting, transportation, and storage of biomass. Additionally, a spreadsheet-based model was developed for students to learn about financial budgets, energy budgets, and carbon budgets for a variety of bioenergy cropping systems in different geographical locations. The model-generated results allow for comparison economic and environmental sustainability among farms in different regions. Student evaluations of the instrument showed high student interest and demonstrated the tool's effectiveness in students' motivation to learn about bioenergy systems to prepare for prospective careers in the field (Thelen et al., 2012).

In another example, Holley (2009) determined a set of best practices related to interdisciplinarity, and Table 5.1 illustrates how the curriculum and educational model researched in the present study embody these conventions.

Table 5.1

*Best Practices for Interdisciplinarity in Higher Education with Examples from This Study*

| Practice | Rationale for Practice | Present Study Characteristics |
|---|---|---|
| Student-centered pedagogy | Encourages students' independence and critical-thinking skills; allows students' interest to shape issues of application | The required research/service learning component is chosen based on student interest, allowing them to leverage their strengths. |
| Focus on Problem- or Theme-Based learning | Shifts role of curriculum from mastery of disciplinary content to critical integration of multiple bodies of knowledge relative to a specific question | With the common goal of sustainable development in regards to energy produced from biomass, students from diverse fields come together to address problems and propose solutions. Moreover, the interdisciplinary minor format enables specialization (major), while providing exposure to broader, yet relevant, content knowledge. |
| Curriculum shaped through a variety of interdisciplinary learning experiences | Recognizes that learning does not occur solely in a formal classroom environment or through formal faculty-student exchanges; recognizes the shifting epistemological boundaries (internal and external to the university) that affect the acquisition of knowledge | The resulting model highlights this by including field trips, internships, outreach opportunities, and research experiences. |

Table 5.1 (Continued)

| | | |
|---|---|---|
| Culminating capstone project or senior portfolio | Gives students the opportunity to apply their skills to a particular problem or topic; allows for a greater focus to interdisciplinary curriculum; sets measureable learning outcomes | In addition to the required research component of the original minor, the new bioinnovations minor also offers the option for service learning/outreach. |
| Focus on collaborative learning rather than mastery of particular content | Recognizes the value to be gained from interaction with multiple groups, including faculty, peers, and community | A combination of interdisciplinary faculty, course content, and student make-up, in combination with opportunities for group work and networking with industry and other professionals, addresses this focus. |
| Use of independent study, internships, and experiential learning | Offers students the opportunity for theory to practice understanding gained through application | Both the traditional research component and service –learning capstone project speak to this type of learning, as well as internship and outreach opportunities. |
| Goal to prepare students for a complex modern, interdisciplinary future | Encourage students' engagement with social problems; facilitates the application of students' knowledge to contemporary issues | Energy security and climate change are complex, interdisciplinary issues that confront the world in the 21st Century, both of which are addressed through bioenergy and bioeconomy education. |
| Dedicated organizational and physical space | Offers institutional legitimacy and facilitates contact among individuals who might otherwise be spread across campus | The bioenergy minor at OSU is offered through the BioResource Research program, which maintains a student resource room/lounge for interaction outside of the classroom. |

Source: Adapted from Holley (2009).

Furthermore, Holley (2009) describes the specific characteristics of an interdisciplinary curriculum. These items are described in Table 5.2, including how they are exemplified in the current model.

Table 5.2

*Characteristics of an Interdisciplinary Curriculum with Examples*

| Component | Purpose | Rationale | Present Study Examples |
|---|---|---|---|
| Faculty | Commonly work in collaboration or in a team-teaching situation | Enables individual faculty to draw on their respective expertise and to collectively contribute to students' development | Guest speakers and faculty research/outreach mentors are experts in their field and contribute regularly to student learning. |
| Syllabi, Course structure | Organized by key facts from contributing disciplines as well as the underlying theme or problem of the course | Allows for a focused breadth of topic and concentration on course rationale | See Appendices J-K. |
| Constituent disciplines | Differing and unique perspectives to approach a common theme or problem | Rather than mastery of specific disciplinary content, encourages a multidimensional approach to a particular question | By offering this degree in the form of a minor, students have a specialization/major and many opportunities for multidisciplinary interaction with other students. |
| Integration | Emphasizes the shared theme or problem that unites the constituent disciplines | Enables holistic thinking whereby students can use various disciplinary perspectives related to a problem | Systems thinking is promoted whereby students examine the linkages and interactions between the components and are "empathetic" to how their field fits into the bigger picture |

Source: Adapted from Holley (2009).

In an investigation on undergraduate bioenergy education in Taiwan, where bioenergy comprises the majority of renewable energy use, Tsai (2012) describes two existing programs and their curricular components. A review of the topics covered shows many similarities among these programs and the curriculum framework and model structure of bioenergy education developed through the present study. For instance, conversions, biomass production, types of bioenergy, engineering, chemistry, and an "innovative" bioenergy project are common items. Moreover, the suggestions that Tsai (2012) makes for innovative approaches to bioenergy education to meet industry needs and improve public awareness are also addressed. These recommendations and their relevance to the present study are displayed in Table 5.3.

Table 5.3

*Innovative Suggestions for Bioenergy Education Development and How They Are Addressed by the Present Study's Model*

| Tsai Suggestions | How it is addressed in the current study |
|---|---|
| Incorporating some basic courses into the bioenergy program (e.g. chemistry, physics, biology, engineering, thermodynamics, environmental sciences) | These items are included under the curriculum framework themes of *Energy Basics, Non-Bioenergy-Specific Fundamentals,* and *Environmental Impacts.* |
| Transforming bioenergy education into an undergraduate degree program in bioenergy | Although there are a variety of bioenergy certificate and graduate programs, as well as traditional degrees, such as chemical engineering, that incorporate bioenergy aspects, this model results in an undergraduate minor degree in bioenergy. |
| Implementing distance learning courses | One of the core required courses for the bioenergy minor at OSU has been converted to an eCampus course, with plans to do this for another core course, and many of the course lectures are available on an open-access YouTube channel. |
| Combining informal science education into the professional education program | Although "informal science education" most often refers to learning at museums, field trip to facilities that demonstrate application of content knowledge in "real life", as done in the bioenergy minor, also accomplishes this objective. |

Source: Adapted from Tsai (2012); Jennings (2009).

In order to demonstrate how the final recommended framework could be utilized to organize bioenergy course components, BRR 250 topics (Table 4.2) were mapped to framework themes (Table 5.4). This exemplifies how the framework can shape a comprehensive curriculum, as well as reduce redundancy of topics. Well-defined themes also ensure that the topics deemed most important by industry and academia experts are covered. For example, *Energy Basics* and *Bioproducts* were not discussed in the

Introduction to Bioenergy course (BRR 250). As previously mentioned, this has been updated based on the findings from this study.

Table 5.4

*BRR 250 Topics and Where they could be Included in the Final Recommended Framework*

| **Lecture Title** | **Example topics** | **Framework Theme** |
|---|---|---|
| Introduction to Bioenergy | · Bioenergy history and context<br>· Carbon sources: petroleum vs. biomass<br>· Basic chemistry<br>· Conversions: Thermal, chemical, biological, and mechanical<br>· Barriers to current bioenergy success | · Current Technologies<br>· Non-Bioenergy-Specific Fundamentals<br>· Conversions |
| Feedstocks and Conversion | · Biomass composition: cellulose, hemicellulose, lignin<br>· Examples of feedstocks<br>· Basic chemistry: sugar vs. starch<br>· Pretreatment<br>· Enzymes | · Biomass Composition<br>· Biomass Production |
| Life Cycle Analysis (LCA) and Sustainability | · $1^{st}$, $2^{nd}$, $3^{rd}$ generation biofuels<br>· Social, environmental, economic sustainability<br>· Use of resources in processing (e.g. water, energy)<br>· LCA start/end points (i.e. cradle to grave, gate, or cradle)<br>· Consequential vs. Attributional LCA<br>· LCA modeling and software options | · Environmental Impacts (including Life Cycle Analysis)<br>· Societal Issues |
| Bioenergy Policy and Regulations | · Role of policy<br>· Energy as a marketable public good<br>· Energy security<br>· Lack of national carbon tax<br>· Federal vs. regional policy<br>· Incentives and mandates<br>· Case studies where policy had unintended outcomes<br>· Energy Policy Act of 2005 and Energy Independence and Security Act (EISA), 2007 | · Policy<br>· Bioenergy Market |
| Business of Bioenergy | · Entrepreneurship<br>· Risk analysis | · Business-Related Knowledge |

Source: Author's own.

Research similar to the Delphi study components of the present study was done by Wang, Chen, and Lee (2012) in Taiwan, which was only discovered after the completion of this research, as an unofficially-published (ResearchGate) conference poster presentation. This Delphi process resulted in a list of 43 competencies (Table 5.5) that were classified under the following 9 themes: feedstock, chemistry, biology, power and heat, manufacturing process, information collection and analysis, policy and rules, green energy concepts, and attitude.  Although comparable to the framework that resulted from this study, the themes differ in both title and quantity.  However, each of the competencies listed could be categorized under the themes deemed essential in this study, and the more general items, such as "information collection and analysis", are addressed in the research experience and specific BRR courses required for the minor at OSU (e.g. Data Presentation, Thesis).  It is notable that this study, conducted in 2012, lacks a bioproducts mention, which also occurred in the first Delphi study presented in this dissertation, conducted in 2014.

Table 5.5

*Example Bioenergy Competencies*

| |
|---|
| 1. Be familiar with properties and applications of various biomass feedstock. |
| 2. Understand production and harvest method of various biomass feedstock |
| 3. Be familiar with storage and transportation of various biomass feedstock. |
| 4. Have basic knowledge of general chemistry and physical chemistry. |
| 5. Have basic knowledge of organic chemistry and biochemistry. |
| 6. Be familiar with physiochemical and biological conversion technology of biomass. |
| 7. Be familiar with thermochemical conversion technology of biomass. |
| 8. Be acquainted with the principles and operations of analytical chemistry and instrumental analysis. |
| 9. Have the knowledge about varieties and characteristics of bioenergy related microorganisms. |
| 10. Have basic knowledge on microorganism metabolism. |
| 11. Have basic knowledge on molecular biology and genetic modification. |
| 12. Be familiar with aseptic processing, fermentation and cell culture techniques. |
| 13. Have basic knowledge on power generation methods and systems. |
| 14. Understand current and future technology of electricity generation from biomass. |
| 15. Be acquainted with the combustion and cofiring technologies of biomass. |
| 16. Be familiar with the basic knowledge of power generation system and utilization of heat from biomass. |
| 17. Be familiar with different types of energy products derived from biomass and their production process. |
| 18. Be familiar with concepts of energy and material balance and related calculation. Understand the importance of energy efficiency in bioenergy production. |
| 19. Understand thermodynamics and reaction kinetics in thermochemical treatments. |
| 20. Understand the principle of operation units in bioenergy production process. |
| 21. Be acquainted with the equipments [sic] in bioenergy process and their selection criteria. |
| 22. Know how to conduct economic, energy, and environmental benefit assessments |
| 23. Have knowledge on process design, integration and improvement |
| 24. Be capable of collecting, reading, understanding and summarizing up-todate knowledge and market information in bioenergy sector. |
| 25. Be capable of realizing the types of feedstock, product, and process with local advantage |
| 26. Be capable of analyzing local and global bioenergy industry status. |
| 27. Understand the energy policies and renewable energy subsidies of the nation. |
| 28. Understand the agricultural policies and subsidies of the nation. |
| 29. Understand the legislation related to biofuels. |
| 30. Be familiar with the nation's standards and regulation on fuels. |
| 31. Have knowledge on policies, rules and regulations on industrial safety and environmental protection. |
| 32. Have knowledge on carbon right and carbon taxes and related rules and regulation. |
| 33. Understand that bioenergy has the merits of replacing fossil fuels and mitigating carbon dioxide emission. |
| 34. Understand that the development of bioenergy industry should not jeopardize food supply and farm land supply. |
| 35. Understand that localization should be considered when developing bioenergy industry. |
| 36. Have the concepts and knowledge in using renewable energy. |
| 37. Work with mission, enthusiasm, and dedication. |
| 38. Have the ability and enthusiasm in self-learning. Be willing to strengthen one's own professional knowledge and skills. |
| 39. Be capable of understanding the knowledge of other disciplines. |
| 40. Be able to communicate with consumers and people of different disciplines. |
| 41. Be a person with integrity and ethics. |
| 42. Be aware of work safety and health protection. |
| 43. Be able to research and innovate. |

Source: Adapted from Wang, Chen, and Lee (2012). Conducted in Taiwan.

**Implications**

The overarching aim of this research was to provide insight and a foundation for developing educational programs in order to generate a capable and well-prepared bioenergy workforce. As emphasized by Wallman (2013),

> the effort to develop and implement biomanufacturing training programs, to identify the skill sets needed for success in the emerging biofuels and biobased products industries, and to provide students with the appropriate classroom, laboratory, and internship experience and opportunities has greatly benefited from, and in many cases been made possible through collaboration and support from industry partners (p.275)

For this reason, opinions of bioenergy minor students and experts in industry and academia were systematically collected and analyzed quantitatively and qualitatively to establish a college-level curriculum framework and recommended model for bioenergy education. Gaining insight into bioenergy education begins to lay a base to build upon in the future.

The resulting bioenergy education framework can be used for the following:

- As guidance for establishing new programs
- As a starting point to begin the discussion around standardization in bioenergy education
- To design instruments to measure student learning
- To evaluate and assess educational training programs
- As a baseline representing the field in 2014 to track changes and evolution of the field (as in the case of the addition of Bioproducts in 2015)
- To contribute to the nascent body of literature on bioenergy education and associated curriculum development

- To organize competencies necessary for employees to be productive in various positions related to different bioenergy technologies
- As a resource to design educational programming for other components of the bioeconomy

**Recommendations**

Based on synthesis of the existing literature, the Delphi studies, and the case study, the author recommends the following for bioenergy education:

- Efforts should be made to standardize bioenergy education at the national level, and ultimately, the global level
- The curricula should be interdisciplinary
- Experiential learning should be incorporated through field trips, service-learning, research experiences, capstone projects, outreach, and/or internships
- Training should be offered as an add-on (e.g. minor or certificate) to a traditional major degree to ensure depth of expertise, as well as general exposure to relevant topics
- Curricula should be updated regularly by consulting with industry and other stakeholders to identify changing needs and keep training programs current
- New and existing programs should  be broadly and enthusiastically advertised
- Industry connections should be maintained, improved, and/or established so students are aware of job opportunities and employers are aware of the training provided to students
- Courses should be team taught to ensure expertise in content areas
- Courses and programs should be made available as distance/eCampus courses to increase overall enrollment from geographically dispersed participants
- Institutions should seek ways to incentivize mentors to participate in experiential learning experiences, and departmental faculty members to contribute to interdisciplinary degree programs

- Financial aid should be sought through grants from government and private corporations to provide scholarships to attract talented students and cover costs for research materials, paid internships, field trip transportation, etc.
- Future research efforts should attempt to determine the specific employee competencies needed for significant positions related to salient bioenergy technologies

**Conclusion**

In conclusion, based on results from the present study, in conjunction with other empirical and theoretical research, the author proposes the following model (Figure 5.1) for bioenergy education to generate a capable and effective workforce in the field. The curriculum framework that resulted from the combined Delphi studies in the present study would be included in the "Framework Items" (dark blue square in down arrow). It provides a starting point and should not remain static. This framework can begin to assist in standardizing education in the field and can provide structure to organize specific competencies required of bioenergy employees. Once determined, appropriate competencies required for specific technologies and occupations could be categorized under the relevant framework theme. Prompted by the recognition that collaborative education is one of the five cornerstones of the anticipated bioeconomy (El-Chichakli et al., 2016), it is the author's hope that this model may ultimately contribute to overall bioeconomy education as well.

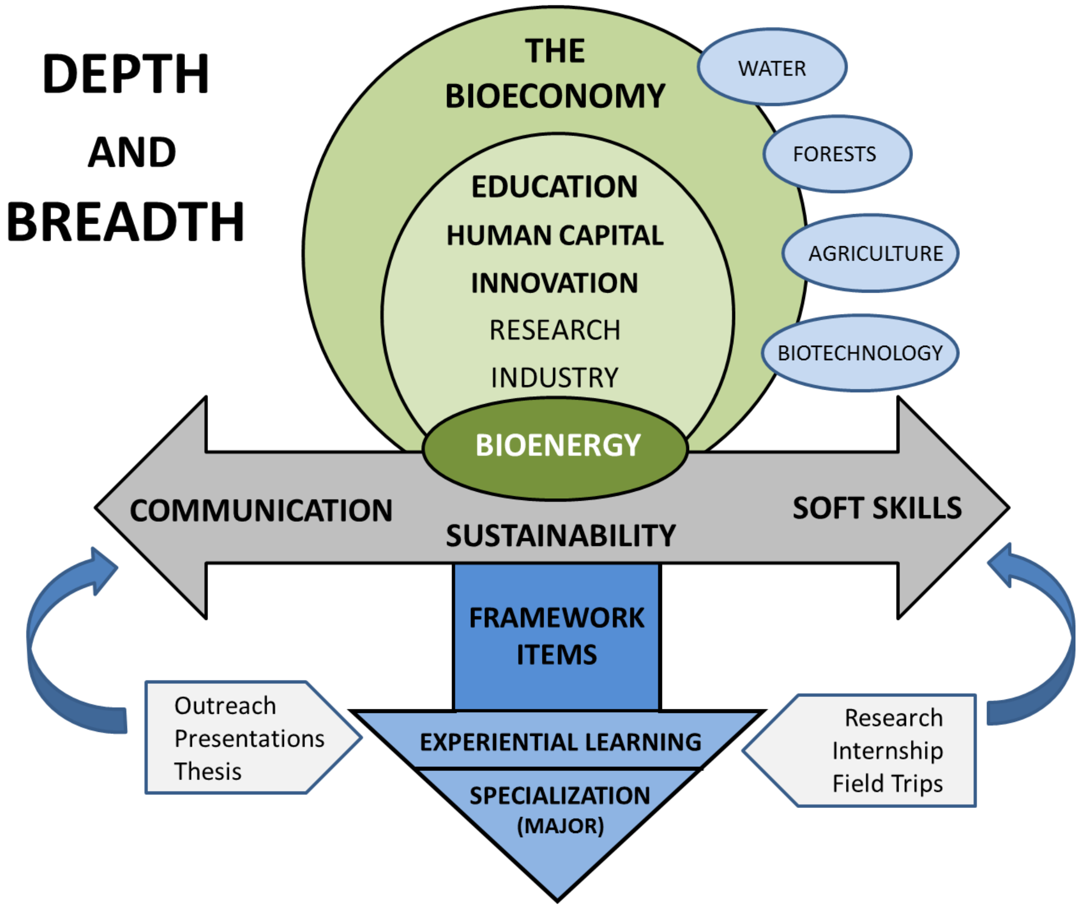


*Figure 3.1*. A proposed model for bioenergy education.

This model presents water, forests, agriculture, biotechnology, and bioenergy as the major resources, technologies, and sciences that comprise the bioeconomy (pale blue). At the core of the bioeconomy are education, human capital, innovation, research, and industry, which are fundamental for a successful bioeconomy. The horizontal (dark gray) double-ended arrow represents the breadth of aptitudes, and the three-part down arrow (dark and light blue) signifies the depth of content knowledge and experience students should possess to be effective future employees. Finally, the light gray shapes indicate the types of activities that students could participate in, in order to gain experience. In turn, these experiential learning activities can strengthen (represented by the curved arrows) their breadth of capabilities. Source: Author's own.

**Bibliography**

Agar, D., Wihersaari, M., Jämsén, M., Ratia, H., & Päällysaho, J. (2011). International Bioenergy Education in Europe–An Overview. Research Reports In Biological And Environmental Sciences, University Of Jyväskylä. Retrieved 4/4/15 from https://core.ac.uk/download/pdf/15744000.pdf.

Amezaga, J. M., Bird, D. N., & Hazelton, J. A. (2013). The future of bioenergy and rural development policies in Africa and Asia. *Biomass and Bioenergy*, *59*, 137-141.

Armstrong, J. S. (Ed.). (2001). *Principles of forecasting: A handbook for researchers and practitioners* (Vol. 30). Springer Science & Business Media.

Ashton, R. H. (2000). A review and analysis of research on the test-retest reliability of professional judgment. *Journal of Behavioral Decision Making*, *13*(3), 277.

Baker, J., Lovell, K., & Harris, N. (2006). How expert are the experts? An exploration of the concept of 'expert' within Delphi panel techniques. *Nurse Researcher*, *14*(1), 59-70.

Bardecki, M. J. (1984). Participants' response to the Delphi method: An attitudinal perspective. *Technological Forecasting and Social Change*, *25*(3), 281-292.

Barrett, E. (2007). Experiential learning in practice as research: Context, method, knowledge. *Journal of Visual Art Practice*, *6*(2), 115-124.

Barry, A., & Born, G. (2013). *Interdisciplinarity: Reconfigurations of the Social and Natural Sciences*. Routledge.

Becker, D. R., Skog, K., Hellman, A., Halvorsen, K. E., & Mace, T. (2009). An outlook for sustainable forest bioenergy production in the Lake States. *Energy Policy*, *37*(12), 5687- 5693.

Bittle, S., Rochkind, J., & Ott, A. (2009). The Energy Learning Curve. Retrieved 5/1/15 from http://www.publicagenda.org/files/energy_learning_curve.pdf.

Boix Mansilla, V., Miller, W. C., & Gardner, H. (2000). On disciplinary lenses and interdisciplinary work. *Interdisciplinary curriculum: Challenges to implem*entation, 17-38. New York: Teachers College Press.

Boje, D. M., & Murnighan, J. K. (1982). Group confidence pressures in iterative decisions. *Management Science*, *28*(10), 1187-1196.

Bolger, F., & Wright, G. (2011). Improving the Delphi process: Lessons from social psychological research. *Technological Forecasting and Social Change*, *78*(9), 1500-1513.

Brown, S., Pyke, D., & Steenhof, P. (2010). Electric vehicles: The role and importance of standards in an emerging market. *Energy Policy*, *38*(7), 3797-3806.

Brown, T. (2005). Strategy by design. *Fast Company*, *95*, 52-54.

Buxton, Bill. (2009). Innovation Calls for I-Shaped People. Business Week. Insight Section. July 13, 2009.

Casimiro, L., MacDonald, C. J., Thompson, T. L., & Stodel, E. J. (2009). Grounding theories of W (e) Learn: A framework for online interprofessional education. *Journal of Interprofessional Care*, *23*(4), 390-400.

Cataldo, Marcelo & Carley, Kathleen & Argote, L. (2001). The Effect of Personnel Selection Schemes on Knowledge Transfer. CASOS Working Paper.

Choudaha, R. (2008). *Competency-base curriculum for a Master's program in SSME: an online Delphi study* (Doctoral Dissertation).

Clayton, M. J. (1997). Delphi: a technique to harness expert opinion for critical decision-making tasks in education. *Educational Psychology*, *17*(4), 373-386.

Collins, H.M. and Evans, R.J. (2002). The third wave of science studies: Studies of expertise and experience, *Social Studies of Sciences*, *32*(2), 235-296.

Communiqué: Making bioeconomy work for sustainable development, Global Bioeconomy Summit, Berlin, Germany, November 2015. Retrieved 5/4/2017 from http://gbs2015.com/fileadmin/gbs2015/Downloads/Communique_final.pdf.

Crowe, M., & Brakke, D. (2008). Assessing the impact of undergraduate research experiences on students: an overview of current literature. *Council on Undergraduate Research Quarterly*, *28*(1), 43-50.

Dewey, J. (1938). *Experiential Education*. New York: Collier.

Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. *Management Science*, *9*(3), 458-467.

Domac, J., Healion, K., Lunnan, A., Madlener, R., Nilsson, S., Richards, K., White, B., Yagishita, T., & Segon, V. (2004, January). Educational Work of Iea Bioenergy Task 29: Socio-Economic Drivers in Implementing Bioenergy Projects. In 2nd World Biomass Conference-Biomass for Energy, Industry and Climate Protection (pp. 10-14).

Donofrio, N., Spohrer, J., & Zadeh, H. S. (2010). Research-driven medical education and practice: A case for T-shaped professionals. *MJA Viewpoint*.

Doran, M. (2004). Ireland: developing the bioenergy industry. *Biocycle*, *45*(4), 75-78.

Eitel, K. B., Hougham, J., Laninga, T., Fizzell, G., Schon, J., & Hendrickson, D. (2010). Teacher professional development for energy literacy: A comparison of two approaches. *Sustainability Education, 8*, 1-24.

Felmingham, S. (August, 2013). *T-shaped Thinkers: Drawing and its role in art school professional practice.* Paper presented at DRN Conference, Loughborough University.

Firestone, William A. (1993). Alternative arguments for generalizing from data as applied to qualitative research. Educational Researcher, *22*(4), 16-22.

Gentile, J.M. (2000). Then and now: A brief view of Hope College today. In M.P. Doyle (Ed.) Academic Excellence. Tuscon, AZ: Research Corporation.

Gilbert, B. L., Banks, J., Houser, J. H., Rhodes, S. J., & Lees, N. D. (2014). Student development in an experiential learning program. *Journal of College Student Development*, *55*(7), 707-713.

Gray, B. (1989). *Collaborating: Finding Common Ground for Multiparty Problems.* Jossey-Bass, San Francisco.

Green, B. P., Graybeal, P., & Madison, R. L. (2011). An exploratory study of the effect of professional internships on students' perception of the importance of employment traits. *Journal of Education for Business*, *86*(2), 100-110.

Gruenewald, D. A. (2003). The best of both worlds: a critical pedagogy of place. *Educational Researcher*, *32*(4), 3-12.

Guest, D. The hunt is on for the Renaissance man of computing. The Independent, London, September 17, 1991.

Guest, C., Healion, K., & Hoyne, S. (2003). Bioenergy Education and Training in Ireland–Experience and Future Priorities. *Socio-Economic Drivers in Implementing Bioenergy Projects: Education and Promotion*.

Gupta, U. G., & Clarke, R. E. (1996). Theory and applications of the Delphi technique: A bibliography (1975–1994). *Technological Forecasting and Social Change*, *53*(2), 185-211.

Guterman, L. (2007). What good is undergraduate research, anyway?. *Chronicle of Higher Education*, *53*(50), 11.

Halder, P., Pietarinen, J., Havu-Nuutinen, S., & Pelkonen, P. (2010). Young citizens' knowledge and perceptions of bioenergy and future policy implications. *Energy Policy*, *38*(6), 3058- 3066.

Halder, P. (2015). An overview of science teachers' knowledge of bioenergy and the need for future research: A case from India. *Progress in Clean Energy, 2,* 59-64.

Hansen, M. T., & Von Oetinger, B. (2001). Introducing T-shaped managers: Knowledge management's next generation. *Harvard Business Review, 79*(3), 106-16.

Hogarth, R. M. (1977). Methods for aggregating opinions. *Decision Making and Change in Human Affairs*, 231-255.

Holley, K. A. (2009). *Understanding interdisciplinary challenges and opportunities in higher education.* San Francisco, CA: Jossey-Bass.

Hu, S., Scheuch, K., Schwartz, R. A., Gayles, J. G., & Li, S. (2008). *Reinventing undergraduate education: Engaging college students in research and creative activities*. San Francisco, CA: Jossey-Bass.

Hungerford, H., Peyton, R. B., & Wilke, R. J. (1980). Goals for curriculum development in environmental education. *The Journal of Environmental Education*, *11*(3), 42-47.

Hurst, J. L., Thye, A., & Wise, C. L. (2014). Internships: The key to career preparation, professional development, and career advancement. *Journal of Family & Consumer Sciences*, *106*(2), 58-62.

Iansiti, M. (1993). Real-world R&D: Jumping the product generation gap. *Harvard Business Review*, *71*(3), 138-147.

Jennings, P. (2009). New directions in renewable energy education. *Renewable Energy, 34*(2), 435-439.

Kandpal, T. C., & Broman, L. (2014). Renewable energy education: A global status review. *Renewable and Sustainable Energy Reviews*, *34*, 300-324.

Kloser, M. (2014). Identifying a core set of science teaching practices: A Delphi expert panel approach. *Journal of Research in Science Teaching, 51*(9), 1185-1217.

Kolb D. (1984). *Experiential learning as the science of learning and development*. Englewood Cliffs, NJ: Prentice Hall.

Landetta, J. (2006). Current validity of the Delphi method in social sciences. *Technological Forecasting and Social Change, 73*(5), 467-482.

Lang, P. J. (1995). The emotion probe: Studies of motivation and attention. *American Psychologist*, *50*(5), 372.

Leonard-Barton, D. (1995). *Wellsprings of knowledge*. Boston, MA: Harvard Business School Press.

Levy, F, & Murnane, R. J. (2004). *The new division of labor: how computers are creating the next job market*. Princeton, NJ: University Press.

Lewis, L. H., & Williams, C. J. (1994). Experiential learning: Past and present. *New Directions for Adult and Continuing Education*, *62,* 5-16.

Liu, W., Lund, H., Mathiesen, B. V., & Zhang, X. (2011). Potential of renewable energy systems in China. *Applied Energy*, *88*(2), 518-525.

Lopatto, D. (2003). The essential features of undergraduate research. *Council on Undergraduate Research Quarterly*, *24*, 139-142.

Ludwig, B. (1997). Predicting the future: Have you considered using the Delphi methodology? *Journal of Extension, 35*(5).

Madhavan, R., & Grover, R. (1998). From embedded knowledge to embodied knowledge: New product development as knowledge management. *The Journal of Marketing*, 1-12.

Maglio, P. P., Srinivasan, S., Kreulen, J. T., & Spohrer, J. (2006). Service systems, service scientists, SSME, and innovation. *Communications of the ACM*, *49*(7), 81-85.

Malone, K., Harmon, A. H., Dyer, W. E., Maxwell, B. D., & Perillo, C. A. (2014). Development and evaluation of an introductory course in sustainable food and bioenergy systems. *Journal of Agriculture, Food Systems, and Community Development*, *4,* 1-13.

Mathews, J. T. (1989). Redefining security. *Foreign Affairs*, *68*(2), 162-177.

Mathews, J. A. (2008). Energizing industrial development. *Transnational corporations, 17*(3), 59-84.

McKenna, H. P. (1994). The Delphi technique: A worthwhile research approach for nursing? *Journal of Advanced Nursing*, *19*(6), 1221-1225.

Mitchell, V. W. (1991). The Delphi technique: An exposition and application. *Technology Analysis & Strategic Management*, *3*(4), 333-358.

Mitra, M., Nagchaudhuri, A., & Rutzke, C. (2013). Energizing the STEAM curricula with bioenergy and bioproducts. In 2013 proceedings of the American Association of Engineering Education, Atlanta, June 2013.

Moore, C.M. (1987). *Group techniques for idea building*. California: Sage.

Morello, D., & Libman, P. (2005). The IT professional outlook: Where will we go from here. *Gartner Report*, *14*, 84.

Murry, J. W., & Hammons, J. O. (1995). Delphi-a versatile methodology for conducting qualitative research. *Review of Higher Education*, *18*(4), 423-436.

National Association of College and Employers [NACE]. (2011). *NACE Research: Job Outlook 2012*. Bethlehem, PA: Author. Retrieved 5/12/15 from https://www.uwsuper.edu/career/students/upload/Job-Outlook-2012-Member-Version-1.pdf

Newell, W. H. (2007). Six arguments for agreeing on a definition of interdisciplinary studies. *Association for Integrative Studies Newsletter*, *29*(4), 1-4.

Nissani, M. (1997). Ten cheers for interdisciplinarity: The case for interdisciplinary knowledge and research. *The Social Science Journal*, *34*(2), 201-216.

Nowack, M., Endrikat, J., & Guenther, E. (2011). Review of Delphi-based scenario studies: quality and design considerations. *Technological Forecasting and Social Change*, *78*(9), 1603-1615.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, *40*(7), 692-720.

Palmer, C., & Ottley, S. (1990). *From potential to reality:'hybrids'-a critical force in the application of information technology in the 1990s*. British Computer Society.

Pasztor, J. & Kristoferson, L. (1990). *Bioenergy and the environment.* Boulder, CO: Westview Press.

Patel, Smit. (n.d.). T-shaped person. Retrieved 5/27/16 from http://smitpatel.com/entrepreneurs-should-be-t-shaped/.

Qu, M., Ahponen, P., Tahvanainen, L., Gritten, D., Mola-Yudego, B., & Pelkonen, P. (2012). Practices and perceptions on the development of forest bioenergy in China from participants in national forestry training courses. *Biomass and Bioenergy*, *40*, 53-62.

Quendler, E., & Lamb, M. (2016). Learning as a lifelong process-meeting the challenges of the changing employability landscape: Competences, skills and knowledge for sustainable development. *International Journal of Continuing Engineering Education and Life Long Learning*, *26*(3), 273-293.

Ransom, C. & Maredia, K. (2012). Building human resources in bioenergy: An international training program at Michigan State University. *Journal of International Agricultural and Extension Education*, *19*(2), 10-13.

Ray, J., & Kafka, S. (2014). Life in college matters for life after college. *Gallup Poll Briefing, 3.*

Rhoten, D., Boix Mansilla, V., Chun, M., & Klein, J. T. (2006). Interdisciplinary education at liberal arts institutions. *Teagle Foundation White Paper. Retrieved December2016 from* http://info.ncsu.edu/strategicplanning/files/2010/10/2006ssrcwhitepaper.pdf.

Rieger, W. G. (1986). Directions in Delphi developments: Dissertations and their quality. *Technological Forecasting and Social Change*, *29*(2), 195-204.

Rohracher, H. (2010). Biofuels and their publics: The need for differentiated analyses and strategies. *Biofuels*, 1(1), 3-5.

Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education*, *21*(4), 409-424.

Rowe, G., & Wright, G. (1999). The Delphi technique as a forecasting tool: issues and analysis. *International Journal of Forecasting*, *15*(4), 353-375.

Sackman, H. (1974). *Delphi assessment: Expert opinion, forecasting, and group process.* Santa Monica, CA: Rand Corp.

Scheer, S. D., Hall, D., & Wright, J. (2012, October). Development and Dissemination of Bioenergy Educational Curriculum for Children. Presented at SunGrant Initiative National Conference. New Orleans, Louisiana.

Schröder, P., Herzig, R., Bojinov, B., Ruttens, A., Nehnevajova, E., Stamatiadis, S., ... & Vangronsveld, J. (2008). Bioenergy to save the world. *Environmental Science and Pollution Research*, *15*(3), 196-204.

Seymour, E., Hunter, A. B., Laursen, S. L., & DeAntoni, T. (2004). Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. *Science Education*, *88*(4), 493-534.

Shahbazi, A., & Schimmel, K. (2006). New Opportunities for Interdisciplinary Research and Education in Bioenergy. 9th International Conference on Engineering Education, San Juan, Puerto Rico, July 2006. Retrieved 5/11/14 from http://www.ineer.org/events/icee2006/papers/3122.pdf.

Singh, S. P., Ekanem, E., Wakefield Jr, T., & Comer, S. (2003). Emerging importance of bio-based products and bio-energy in the US economy: Information dissemination and training of students. *International Food and Agribusiness Management Review*, *5*(3), 14.

Sipilä, K., & Wilén, C. (2012). The structure and achievements of the Bioenergy Network of Excellence. *Biomass and Bioenergy*, *38*, 2-13.

Sissine, F. (2007, December). Energy Independence and Security Act of 2007: A summary of major provisions. Washington DC: Library of Congress Congressional Research Service.

Smáradóttir, S. E., Magnúsdóttir, L., Smárason, B. Ö., Þórðarson, G., Johannessen, B., Stefánsdóttir, E. K., ... & Gunnarsdóttir, R. (2014). *Future opportunities for bioeconomy in the West Nordic countries.* Matis. Retrieved 6/1/2015 from http://www.matis.is/media/matis/utgafa/Bioeconomy-in-the-West-Nordic-countries-37-14.pdf.

Somerville, M. J. (2010). A place pedagogy for 'global contemporaneity'. *Educational Philosophy and Theory, 42*(3), 326-344.

Spelt, E. J., Biemans, H. J., Tobi, H., Luning, P. A., & Mulder, M. (2009). Teaching and learning in interdisciplinary higher education: A systematic review. *Educational Psychology Review*, *21*(4), 365-378.

Spencer, C., & Perry, A. (2015). Helping students maximize their degrees as competitive tools: The value of experiential learning. *The William and Mary Educational Review, 4*(1), 25-33.

Steiner, G., & Posch, A. (2006). Higher education for sustainability by means of transdisciplinary case studies: an innovative approach for solving complex, real-world problems. *Journal of Cleaner Production*, *14*(9), 877-890.

Stewart, J. (2001). Is the Delphi technique a qualitative method? *Medical Education*, *35*(10), 922-923.

Taraban, R. M., & Blanton, R. L. (Eds.). (2008). *Creating effective undergraduate research programs in science: The transformation from student to scientist*. Teachers College Press.

Thompson, D. (2014, August 19). The thing employers look for when hiring recent graduates. *The Atlantic*. Retrieved 5/25/17 from https://www.theatlantic.com/business/archive/2014/08/the-thing-employers-look-for-when-hiring-recent-graduates/378693/.

Toohey, S. (1999). *Designing courses for higher education.* Buckingham: The Society for Research into Higher Education and Open University Press.

United States Department of Agriculture. (2011). Agriculture Secretary Vilsack announces major investments to spur innovation and job creation in research, development and production of next generation biofuels [Press Release]. Retrieved from http://www.usda.gov/wps/portal/usda/usdamediafb?contentid=2011/09/0425.xml&printable=true&contentidonly=true.

United States Department of Energy. Perlack and B.J. Stokes (Leads)(2011). *U.S. billion-ton update: Biomass supply for a bioenergy and bioproducts industry.* Oak Ridge, TN: Oak Ridge National Laboratory.

United States Energy Information Administration. (2013). *Annual energy review*. Retrieved 2/1/14 from http://www.eia.gov/totalenergy/data/annual/index.cfm#summary.

Varner, J. (2014). Scientific outreach: Toward effective public engagement with biological science. *Bioscience, 64,* 333–340.

von der Gracht, H. A. (2008). The Delphi technique for futures research. *The Future of Logistics: Scenarios for 2025*, 21-68.

Vygotsky, L. (1978). *Mind in Society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wallman, M. S., Coleman, P. M., Fino, M., Kainer, D., King, K., Kuehnle, A., & Nedosa, I. (2013). Training technicians to support the bioeconomy: Defining the need; designing and implementing innovative solutions. *Industrial Biotechnology*, *9*(5), 275-281.

Wallsten, T. S., Budescu, D. V., Erev, I., & Diederich, A. (1997). Evaluating and combining subjective probability estimates. *Journal of Behavioral Decision Making*, *10*(3), 243-268.

Warnmer, S. (2007). *Progress in biomass and bioenergy research*. New York, NY: Nova Science Publishers.

Watkinson, I. I., Bridgwater, A. V., & Luxmore, C. (2012). Advanced education and training in bioenergy in Europe. *Biomass and Bioenergy, 38,* 128-143.

Weaver, T. (1971). The Delphi forecasting method. *The Phi Delta Kappan*. *52*(5), 267-271.

Wellman, G. L. (2003). *A Delphi Expert Assessment of Proactive Contracting in an Evolutionary Acquisition Environment*, Unpublished MSc Thesis, Air Force Institute of, Technology, US Air University.

White House. (2012). *National Bioeconomy Blueprint*. Washington, DC, The White House, April.

Xu, X., Goswami, S., Gulledge, J., Wullschleger, S. D., & Thornton, P. E. (2016). Interdisciplinary research in climate and energy sciences. *Wiley Interdisciplinary Reviews: Energy and Environment*, *5*(1), 49-56.

Ziglio, E. (1996). Gazing into the oracle: The Delphi method and its application to social policy and public health. *Jessica Kingsley Publishers, 5*, 3-33.

Zografakis, N., Menegaki, A. N., & Tsagarakis, K. P. (2008). Effective education for energy efficiency. *Energy Policy*, *36*(8), 3226-3232.

Zydney, A. L., Bennett, J. S., Shahid, A., & Bauer, K. (2002). Faculty perspectives regarding the undergraduate research experience in science and engineering. *Journal of Engineering Education*, *91*(3), 291-297.

# APPENDICES

# APPENDIX A

Determining Essential Components of a College-level Bioenergy Curriculum
in the United States Using the Delphi Technique

Invitation and Reminder Email

Dear Colleague,

Recently we sent you an invitation (see below) to participate in a research project entitled: Determining necessary components of K12 and college level bioenergy curricula using the Delphi technique. Your opinion as an expert in the field of bioenergy is crucial for the success of this project. If you would like **to participate**, please click here BY MAY 16, 2014. **Please forward this invitation** to others with advanced knowledge in the field of bioenergy regardless of whether you choose to participate. Due to the interdisciplinary nature of the bioenergy field, we are seeking a variety of participants. (This paragraph only included in reminder email)

==================================================================

Dear Colleague,

We are writing to request your participation in a research project entitled: Determining necessary components of K12 and college level bioenergy curricula using the Delphi technique. The purpose of this letter is to describe the study so you can decide if you would like to participate.

Increasing concern regarding global climate change and national energy security has spurred the quest for viable solutions, and bioenergy has been suggested as an option. In order to sustainably meet our future energy demand, a well-trained workforce capable of meeting impending challenges will be required, and education is key.

The goal of this project is to attain consensus among a panel of bioenergy experts regarding what a bioenergy curriculum should include. In order to achieve this goal, we will be utilizing the Delphi technique. The Delphi technique is a recognized mixed methods approach of gathering data from experienced individuals through an iterative questionnaire process, coupled with controlled feedback. Round 1 will consist of 1-2 open ended questions, and subsequent rounds include Likert-scale responses to the combined panel results from the previous round, as well as the option to provide qualitative comments. The procedure is de-identified in that the identity of participants and their responses are only known by the researchers.

For our study, we envision a maximum of 4 rounds that should take approximately 30 minutes each, and no travel is required.

Should you be willing **TO PARTICIPATE**, click here http://Take the Survey **BY MAY 16** and provide the requested information to be added to the pool of bioenergy experts. This should take you less than five minutes, and all information collected will remain confidential. Not everyone who provides this information will be asked to participate on the expert panel. This study is completely voluntary and you may withdraw at any time; however, due the iterations employed in the Delphi method, the best results are obtained from participants who follow through to completion of the study. Formal consent will be requested during Round 1.

Regardless of whether you choose to take part in this research, **please forward this invitation to others** with advanced knowledge in the field of bioenergy. Due to the interdisciplinary nature of the bioenergy field, we are seeking a variety of participants.

Thank you for your consideration of this initiative. Your participation will contribute to the development of improved bioenergy curricula. If you have any questions, please contact Principal Investigator

Yours sincerely,

Kimi Grzyb
Environmental Sciences PhD Student
Oregon State University
grzybk@onid.oregonstate.edu

Brian Hartman
Science Education PhD Student
Oregon State University
hartmanb@onid.oregonstate.edu

Follow the link to opt out of future emails:
Click here to unsubscribe

# APPENDIX B

Determining Essential Components of a College-level Bioenergy Curriculum in the United States Using the Delphi Technique

Round 1 Survey

College-Level Bioenergy Curriculum Study Consent

Explanation of Research: The goal of this study (funded by the US Department of Agriculture) is to elicit which components a college-level bioenergy curriculum should include. As a participant in the study, you will be asked to complete a series of up to four 30-minute questionnaires that will allow you to express your opinions about the ideal bioenergy curriculum. The first round will consist of ONE open-ended question. In each subsequent round, participants will be asked to rate and/or comment on the results from the previous round. Your participation in this research is important because consensus has not been established regarding what should be taught in bioenergy programs. While we are not offering payment for your participation in this project, we hope our results improve the bioenergy knowledge of students and employees you may work with in the future. In addition, you are helping to establish foundational principles for this emerging field while moving our country towards a more sustainable and independent energy future. This study is voluntary, and there is no penalty for leaving the study at any time. You are also free to decline to answer any question. At any time, you can ask that any identifying information about your participation in the study be destroyed. One potential risk in participating in this type of project is that people could determine your identity. In order to mitigate this risk, only the researchers will know your name and any publications will use your responses confidentially and in a de-identified manner, unless we obtain your specific permission. The security and confidentiality of information collected from you online cannot be guaranteed. Confidentiality will be kept to the extent permitted by the technology being used. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses. If you have any questions about this study, please contact: Katharine G. Field Principal Investigator Oregon State University Kate.Field@oregonstate.edu Phone: (541) 737-1837

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu.

- I agree (1)
- I do not agree (2)

If I agree Is Selected, Then Skip To Thank you for your willingness to par...If I do not agree Is Selected, Then Skip To End of Survey

College-Level Bioenergy Curriculum Study - Round 1 of 3 Thank you for your willingness to participate in this study. Your responses will be consolidated with those of a broad range of other experts to identify the bioenergy concepts that would be essential for students to learn by completion of an undergraduate degree in bioenergy.

Question 1 of 1: Keeping in mind the future of a commercial bioenergy industry, what content knowledge (including social and/or natural sciences) should a student have upon completion of an undergraduate bioenergy curriculum? Please provide a brief description and/or explanation for each item. There is no limit to the number of items you may list.

Upon completion of this study, results will be summarized and published. Your specific responses will remain de-identified, but would you like to be recognized as a member of the expert panel after all rounds have been completed?

- ❍ Yes
- ❍ No
- ❍ Ask me later

If Yes Is Selected, Then Skip To How would you like your name to appea...If No Is Selected, Then Skip To Thank you for participating in the fi...If Ask me later Is Selected, Then Skip To Thank you for participating in the fi...

How would you like your name to appear in print?

Name
Title
Organization

Thank you for participating in the first round of this Delphi study. Your results will be collated with others. In the next round (late June), you will have an opportunity to express your opinion regarding which of these bioenergy concepts are most important. If you have any questions about this study, please contact: Principal Investigator.

# APPENDIX C

Determining Essential Components of a College-level Bioenergy Curriculum
in the United States Using the Delphi Technique

Round 2 Survey

DELPHI STUDY ROUND 2 of 3: Thank you for participating in Round 1 of the college-level bioenergy Delphi study. Your responses were collated with those of other participants and coded for themes. Round 1 expert panel responses revealed the following 14 content knowledge themes (in no particular order): Types of Bioenergy, Logistics, Societal Issues, Bioenergy Market, Environmental Impacts, Biomass Production, Biomass Composition, Conversions, Energy Basics, Current Technologies, Life Cycle Analysis, Policy, Business-Related Knowledge, Non-Bioenergy-Related Fundamentals.

Keeping in mind the future of a commercial bioenergy industry, on the next pages, please rate the importance of including each item in a general college-level bioenergy curriculum using the scale 1 = Non-essential to 5 = Essential. Your responses will be shared anonymously with the rest of the expert panel in Round 3. Please provide relevant additions, modifications, clarifications, and/or justifications in the space provided, if needed. You will also be given the opportunity to express your opinion regarding the structure of bioenergy education. The goal of this study is to attain consensus among a variety of bioenergy experts regarding the essential components of a college-level bioenergy curriculum. Your thoughtful feedback is greatly appreciated!

TYPES OF BIOENERGY Summary: Students should be familiar with a broad range of available and emerging types of bioenergy.

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Types of Bioenergy | | | | | | |

Additions, modifications, clarifications, justifications, if any:

LOGISTICS Summary: Students should understand the planning, implementation, and coordination required for the bioenergy supply-chain. Example panel responses: Determining critical assumptions to enable a meaningful and sustainable supply chain; a holistic approach to the supply chain; feedstock storage and transportation; infrastructure requirements

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Logistics | | | | | | |

Additions, modifications, clarifications, justifications, if any:

SOCIETAL ISSUES Summary: Students should recognize the societal consequences (pros and cons) resulting from a bioenergy industry. Example responses: Traffic; noise; food vs. fuel; rural energy independence; rural demographic historical context; social issues that are driving the role of biomass today; misconceptions about biomass; convincing people to choose bioenergy options; employment benefits; food and land price increases; increased national security

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Societal Issues | | | | | | |

Additions, modifications, clarifications, justifications, if any:

BIOENERGY MARKET  Summary: Students should be familiar with the current and projected bioenergy market.  Example panel responses: How the technology market works and is expected to work; carbon credit trading; how renewable fuels and chemicals can be best aligned with the existing model; replacing or co-processing fossil resources; value chain; what affects decisions about adoption of bioenergy production systems

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Bioenergy Market | | | | | | |

Additions, modifications, clarifications, justifications, if any:

ENVIRONMENTAL IMPACTS  Summary: Students should be familiar with environmental impacts related to bioenergy production.  Example panel responses: Climate change; land use change; sustainability; environmental ethics; invasive species; utilization of nutrients; carbon cycle; environmental/water law

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Environmental Impacts | | | | | | |

Additions, modifications, clarifications, justifications, if any:

BIOMASS PRODUCTION  Summary: Students should understand the methods involved with producing commercial quantities of biomass.  Example panel responses: Feedstock types; agriculture; silviculture; forestry; aquaculture; crop management; harvest; supply cost curves; soil science; water conservation; erosion control; soil/plant/atmosphere interfaces; plant pathology; pest management; how to determine the amount of biomass that can be sustainably supplied from a given region

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Biomass Production | | | | | | |

Additions, modifications, clarifications, justifications, if any:

BIOMASS COMPOSITION  Summary: Students should know the basic biomass components.  Example panel responses: cellulose; hemicellulose; lignin; ash content; moisture content

| | Non- | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|

| | essential (1) | | | | | |
|---|---|---|---|---|---|---|
| Biomass Composition | | | | | | |

Additions, modifications, clarifications, justifications, if any:

CONVERSIONS Summary: Students should have scientific knowledge of converting biomass to intermediates and end products. Example panel responses: biological; thermal; chemical; residence time and recycle/waste streams; biomass processing

| | Non-essential (1) | (2) | (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Conversions | | | | | | |

Additions, modifications, clarifications, justifications, if any:

ENERGY BASICS Summary: Students should understand the fundamental principles of energy. Example panel responses: Thermodynamic relationships between mass and energy; flow and storage; sources and uses of energy; net energy yield; efficiency and balance; energy content of fuels

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Energy Basics | | | | | | |

Additions, modifications, clarifications, justifications, if any:

CURRENT TECHNOLOGIES Summary: Students should be familiar with current energy production. Example panel responses: Refining and petrochemicals industries; combustion-based technology for heat/power production; role of biomass as a source of renewable energy in the U.S. and around the world; how biomass compares to fossil fuels and other renewables; comparing different energy technology or processes covering capital and operating cost differences, efficiency differences, environmental impact differences

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Logistics | | | | | | |

Additions, modifications, clarifications, justifications, if any:

LIFE CYCLE ANALYSIS Summary: Students should be able to evaluate potential environmental impacts associated with inputs and outputs, and analyze results to make informed decisions. Example panel responses: Accounting of emissions; how greenhouse gas balances and energy balances for biomass systems are assessed; carbon neutrality; systems being used to assess the sustainability of biomass conversion techniques for different end uses; evaluate the environmental footprint of a technology or process and how to compare it to current forms of energy from cradle to grave

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Logistics | | | | | | |

Additions, modifications, clarifications, justifications, if any:

POLICY Summary: Students should be familiar with existing and proposed policies that influence the growth of the industry. Example panel responses: State, regional, national, and global level policies, including past, current, and proposed legislation, regulation impacting on and being impacted upon by Bioenergy; policy environment in effect and under proposal to impact the development of technologies; explanation of the renewable fuels standards, EPA requirements, DOE programs, and other government and NGO supports for biofuels; regulatory and permitting challenges

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Policy | | | | | | |

Additions, modifications, clarifications, justifications, if any:

BUSINESS-RELATED KNOWLEDGE Summary: Students should have a basic understanding of business management and strategy. Please rate the following:

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Finance | | | | | | |
| Economics | | | | | | |
| Risk Analysis | | | | | | |
| SWOT (strengths, weaknesses, opportunities, threats) Analysis | | | | | | |
| Return on Investment Calculations | | | | | | |

Additions, modifications, clarifications, justifications, if any:

NON-BIOENERGY-SPECIFIC FUNDAMENTALS Summary: In addition to the above-mentioned topics, students should also have fundamental coursework and skills. Please rate the following:

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Biology | | | | | | |
| Chemistry | | | | | | |
| Math | | | | | | |
| Physics | | | | | | |
| Ecosystem Ecology | | | | | | |
| Writing Skills | | | | | | |
| Communication Skills | | | | | | |
| Data Analysis using Statistical Techniques | | | | | | |
| Process Modeling | | | | | | |

Additions, modifications, clarifications, justifications, if any:

In addition to content knowledge, themes related to bioenergy education structure emerged. In order to explore this topic further, please rate the extent to which you agree with the following statements using the scale 1 = Strongly Disagree to 5 = Strongly Agree.

| | Strongly DISAGREE (1) | (2) | Neutral (3) | (4) | Strongly AGREE (5) |
|---|---|---|---|---|---|
| The overall goal of a bioenergy curriculum should be to prepare students to be knowledgeable critical thinkers. | | | | | |
| A Multi-disciplinary "Capstone" project would be beneficial - bringing together students from two or more disciplines on teams that would conduct a significant Design or Analysis Project in a Bioenergy field. | | | | | |
| A college level bioenergy curriculum should result in students who are conversant in the terminology, technology, and issues associated with the advancement of bioenergy. | | | | | |
| A college level bioenergy curriculum should produce students who have a deeper expertise in one or more aspects of the bioenergy arena. | | | | | |

Additional comments related to the structure of bioenergy education, if any:

If you have any additional themes, comments, or modifications, please include them here:

# APPENDIX D

Determining Essential Components of a College-level Bioenergy Curriculum
in the United States Using the Delphi Technique

Round 3 Survey

DELPHI STUDY ROUND 3 of 3: Thank you for participating in Round 2 of the college-level bioenergy curriculum Delphi study. To refresh your memory, the following bioenergy content knowledge themes were rated (1 = Non-essential to 5 = Essential): Types of Bioenergy, Logistics, Societal Issues, Bioenergy Market, Environmental Impacts, Biomass Production, Biomass Composition, Conversions, Energy Basics, Current Technologies Life Cycle Analysis, Policy, Business-Related Knowledge, Non-Bioenergy-Specific Fundamentals. Based on feedback from the expert panel, the following modification has been made: Life Cycle Analysis is now included under Environmental Impacts. In this round, you will be provided with the expert panel's mean ratings and standard deviations from the previous round. Please rate each item again while considering the panel's results. If your new rating deviates more than one point on the 5-point Likert-type scale from the mean, PLEASE PROVIDE AN EXPLANATION in the space provided. The goal of this study is to attain consensus among a variety of bioenergy experts regarding the essential components of a college-level bioenergy curriculum. Although consensus has been reached for many of the items, Round 3 data will be used to determine stability between rounds. Your thoughtful feedback is greatly appreciated!

TYPES OF BIOENERGY Summary: Students should be familiar with a broad range of available and emerging types of bioenergy. MEAN = 4.50 STANDARD DEVIATION = 0.90

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Types of Bioenergy | | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:
LOGISTICS Summary: Students should understand the planning, implementation, and coordination required for the bioenergy supply-chain. MEAN = 4.08 STANDARD DEVIATION = 0.67

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Logistics | | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:
SOCIETAL ISSUES Summary: Students should recognize the societal consequences (pros and cons) resulting from a bioenergy industry. MEAN = 4.08 STANDARD DEVIATION = 0.90

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Societal Issues | | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

BIOENERGY MARKET Summary: Students should be familiar with the current and projected bioenergy market. MEAN = 3.92 STANDARD DEVIATION = 1.00

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Bioenergy Market | | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

ENVIRONMENTAL IMPACTS (including Life Cycle Analysis) Summary: Students should be familiar with positive and negative environmental impacts related to bioenergy production and evaluate inputs and outputs to make informed decisions. MEAN = 4.38

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Environmental Impacts | | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

BIOMASS PRODUCTION Summary: Students should understand the methods involved with producing commercial quantities of biomass. MEAN = 4.42 STANDARD DEVIATION = 0.79

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Biomass Production | | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

BIOMASS COMPOSITION Summary: Students should know the basic biomass components. MEAN = 4.33 STANDARD DEVIATION = 0.89

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Biomass Composition | | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

CONVERSIONS Summary: Students should have scientific knowledge of converting biomass to intermediates and end products. MEAN = 4.08 STANDARD DEVIATION = 0.90

| | Non-essential (1) | (2) | (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Conversions | | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

ENERGY BASICS Summary: Students should understand the fundamental principles of energy. MEAN = 4.5 STANDARD DEVIATION = 1.24

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Energy Basics | | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

CURRENT TECHNOLOGIES Summary: Students should be familiar with current energy production. MEAN = 4.17 STANDARD DEVIATION = 0.94

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Current Technologies | | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

POLICY Summary: Students should be familiar with existing and proposed policies that influence the growth of the industry. MEAN = 4.00 STANDARD DEVIATION = 0.95

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Policy | | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

BUSINESS-RELATED KNOWLEDGE Summary: Students should have a basic understanding of business management and strategy. Please rate the following:

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Finance (Mean=3.58, SD=1.00) | | | | | | |
| Economics (Mean=4.00, SD=0.95) | | | | | | |
| Risk Analysis (Mean=3.67, SD=0.98) | | | | | | |
| SWOT (strengths, weaknesses, opportunities, threats) Analysis (Mean=3.42, SD=1.24) | | | | | | |
| Return on Investment Calculations (Mean=4.08, SD=1.00) | | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

NON-BIOENERGY-SPECIFIC FUNDAMENTALS Summary: In addition to the above-mentioned topics, students should also have fundamental coursework and skills. Please rate the following:

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) | No Opinion |
|---|---|---|---|---|---|---|
| Biology (Mean=4.18, SD=0.87) | | | | | | |
| Chemistry (Mean=4.45, SD=0.69) | | | | | | |
| Math (Mean=4.27, SD=1.10) | | | | | | |
| Physics (Mean=4.00, SD=1.05) | | | | | | |
| Ecosystems / Ecology (Mean=4.00, SD=0.94) | | | | | | |
| Writing Skills (Mean=4.36, SD=0.81) | | | | | | |
| Communication Skills (Mean=4.45, SD=1.04) | | | | | | |
| Data Analysis using Statistical Techniques (Mean=4.45, SD=0.93) | | | | | | |
| Process Modeling (Mean=3.90, SD=1.20) | | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

In addition to content knowledge, themes related to bioenergy education structure emerged (e.g. capstone project, case studies, general knowledge vs. specialty area). If you have any additional comments related to the structure of bioenergy education, please include them here:

If you have any additional general comments, please include them here:

# APPENDIX E

Comparing Industry and Academia Priorities in Bioenergy Education: A Delphi Study

Invitation and Reminder Email

Dear ____,

Recently we sent you an invitation (see below) to participate in a research study.
Your opinion as an expert in the field of bioenergy is crucial for the success of this project. (This paragraph only included in reminder emails).

We are writing to request your participation in a research project entitled: Prioritizing Pertinent Components of a College-Level Bioenergy Curriculum Using the Delphi Technique. You are receiving this invitation because you have been identified as an expert in bioenergy.

In order to develop bioenergy into a viable industry, there is an immediate need for a workforce whose education combines interdisciplinary content knowledge with integrated approaches to innovation and problem solving. To meet this need, it is necessary to identify and prioritize the topics that should be included in a college-level bioenergy curriculum.

For this study, we will be utilizing the Delphi technique. The Delphi technique is a recognized mixed methods approach of gathering data from experienced individuals through an iterative questionnaire process, coupled with controlled feedback. Round 1 will consist of a list of 13 items to be rated (1=not important to 5=very important), as well the opportunity to provide additional items and comments. In subsequent rounds, group results will be revealed in aggregate, and you will again be asked to rate each item and be given the opportunity to provide qualitative comments. The procedure is de-identified in that the identity of participants and their responses are only known by the researchers throughout the study.

For our study, we envision a maximum of 4 rounds, initiated in the upcoming weeks, that should take approximately 15 minutes each, and no travel is required.
Please reply by 11/19/15.

Should you be willing **TO PARTICIPATE**:
**Follow this link to the Survey:**Take the Survey

This study is completely voluntary and you may withdraw at any time; however, due the iterations employed in the Delphi method, the best results are obtained from participants who follow through to completion of the study. Formal consent will be requested before you begin Round 1.

Thank you for your consideration of this initiative. Your participation will contribute to the development of improved bioenergy curricula. If you have any questions, please contact the Principal Investigator.
Yours sincerely,

Katharine G. Field
Principal Investigator
Oregon State University

Kimi Grzyb
Environmental Sciences PhD Candidate
Oregon State University

Follow the link to opt out of future emails:
Click here to unsubscribe

# APPENDIX F

Comparing Industry and Academia Priorities in Bioenergy Education: A Delphi Study

Round 1 Survey

Consent: Explanation of Research Study: The goal of this study (funded by the U.S. Department of Agriculture) is to elicit the opinions of bioenergy experts regarding the essential components of a college-level bioenergy curriculum. As a participant in the study, you will be asked to complete a series of up to four 30-minute surveys that will allow you to express your opinions about the ideal bioenergy curriculum. The first survey will consist of a list of 13 items to be rated, as well as 2 open-ended questions. In subsequent rounds, participants will be asked to rate and/or comment on the results from the previous round. Your participation in this research is important to help determine what should be taught in bioenergy programs at the college level to prepare students for careers in the field of bioenergy. While we are not offering payment for your participation in this project, we hope our results improve the bioenergy knowledge of students and employees you may work with in the future. In addition, you are helping to establish foundational principles for this emerging field while moving our country towards a more sustainable and independent energy future. This study is voluntary, and there is no penalty for leaving the study at any time. You are also free to decline to answer any question. At any time, you can ask that any identifying information about your participation in the study be destroyed. One potential risk in participating in this type of project is that people could determine your identity. In order to mitigate this risk, only the researchers will know your name and any publications will use your responses confidentially and in a de-identified manner, unless we obtain your specific permission. The security and confidentiality of information collected from you online cannot be guaranteed. Confidentiality will be kept to the extent permitted by the technology being used. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses. If you have any questions about this study, please contact Principal Investigator. If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board.

- ❍ I agree
- ❍ I do not agree

If I agree Is Selected, Then Skip To Thank you for your willingness to par...If I do not agree Is Selected, Then Skip To End of Survey

Thank you for your willingness to participate in this study. Keeping in mind the future of a commercial bioenergy industry, please rate the importance of including each item in a general college-level bioenergy curriculum using the scale: 1 = Non-essential to 5 = Essential. Themes were determined from a previous study and are presented in no particular order. Aggregate results will be shared anonymously with the rest of the expert panel in Round 2.

| | 1 Non-essential | 2 | 3 Medium | 4 | 5 Essential |
|---|---|---|---|---|---|
| Types of Bioenergy: Students should be familiar with a broad range of available and emerging types of bioenergy | ❍ | ❍ | ❍ | ❍ | ❍ |
| Logistics: Students should understand the planning, implementation, and coordination required for the bioenergy supply-chain | ❍ | ❍ | ❍ | ❍ | ❍ |
| Societal Issues: Students should recognize the societal consequences (pros and cons) resulting from a bioenergy industry | ❍ | ❍ | ❍ | ❍ | ❍ |
| Bioenergy Market: Students should be familiar with the current and projected bioenergy market | ❍ | ❍ | ❍ | ❍ | ❍ |
| Biomass Production: Students should understand the methods involved with producing commercial quantities of biomass | ❍ | ❍ | ❍ | ❍ | ❍ |
| Biomass Composition: Students should know the basic biomass components | ❍ | ❍ | ❍ | ❍ | ❍ |
| Conversions: Students should have scientific knowledge of converting biomass to intermediates and end products | ❍ | ❍ | ❍ | ❍ | ❍ |
| Energy Basics: Students should understand the fundamental principles of energy | ❍ | ❍ | ❍ | ❍ | ❍ |
| Current Technologies: Students should be familiar with current energy production | ❍ | ❍ | ❍ | ❍ | ❍ |
| Policy: Students should be familiar with existing and proposed policies that influence the growth of the industry | ❍ | ❍ | ❍ | ❍ | ❍ |
| Business-Related Knowledge: Students should have a basic understanding of business management and strategy (e.g. finance, economics, risk analysis, return on investment calculations) | ❍ | ❍ | ❍ | ❍ | ❍ |
| Non-Bioenergy-Specific Fundamentals: In addition to bioenergy-specific topics, students should also have fundamental coursework and skills (e.g. biology, chemistry, writing skills, data analysis, statistics, etc.) | ❍ | ❍ | ❍ | ❍ | ❍ |
| Environmental Impacts (including Life Cycle Analysis): Students should be familiar with positive and negative environmental impacts related to bioenergy production and evaluate inputs and outputs to make informed decisions | ❍ | ❍ | ❍ | ❍ | ❍ |

Are there any additional items you would like to add? Please describe below:

Please provide any additional comments here:

# APPENDIX G

Comparing Industry and Academia Priorities in Bioenergy Education: A Delphi Study
Round 2 Survey

DELPHI STUDY ROUND 2: Thank you for your continued participation. To refresh your memory, in Round 1, the following bioenergy content knowledge themes were rated (1= Non-essential to 5 = Essential)

Energy Basics 4.43
Environmental Impacts (including Life Cycle Analysis) 4.30
Policy 4.26
Types of Bioenergy 4.17
Current Technologies 4.13
Non-Bioenergy-Specific Fundamentals 4.13
Societal Issues 4.00
Logistics 3.89
Biomass Composition 3.87
Biomass Production 3.85
Bioenergy Market 3.83
Conversions 3.83
Business-related Knowledge 3.78

Based on feedback from the expert panel, slight modifications have been made to the summaries of some existing themes, and two themes have been added: Bioproducts and Ethics

In this round, you will be provided with the expert panel's mean ratings and standard deviations from the previous round. Please rate each item again while considering the panel's results. If your new rating deviates more than one point on the 5-point Likert-type scale from the mean, PLEASE PROVIDE AN EXPLANATION in the space provided.

The goal of this study is to attain consensus among a variety of bioenergy experts regarding the essential components of a college-level bioenergy curriculum. Although consensus has been reached for many of the items, Round 2 data will be used to determine stability between rounds. In response to comments/questions from the expert panel: Due to the interdisciplinary and emerging nature of the field of bioenergy, it is anticipated that students will have a traditional specialization/major (e.g. engineering, agriculture, etc.) in addition to bioenergy education/training.

Results are intended to inform emerging bioenergy education/training programs to meet the needs of future employers and support students for success in the field of bioenergy. The framework is intended to be applicable to all types of bioenergy (technology neutral) and may be adapted for specific technologies. Your thoughtful feedback is greatly appreciated!

TYPES OF BIOENERGY Summary: Students should be familiar with a broad range of available and emerging types of bioenergy. MEAN = 4.16 STANDARD DEVIATION = 0.95

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Types of Bioenergy | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

LOGISTICS Summary: Students should understand the planning, implementation, and coordination required for the bioenergy supply-chain. MEAN = 3.89 STANDARD DEVIATION = 0.90

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Logistics | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

SOCIETAL ISSUES Summary: Students should recognize the societal consequences (pros and cons) resulting from a bioenergy industry, as well as the concerns associated with consumer acceptance and landowner/producers' willingness to supply biomass. MEAN = 4.00 STANDARD DEVIATION = 0.92

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Societal Issues | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

BIOENERGY MARKET Summary: Students should be familiar with the current and projected bioenergy market. MEAN = 3.83 STANDARD DEVIATION = 0.90

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Bioenergy Market | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

ENVIRONMENTAL IMPACTS (including Life Cycle Analysis) Summary: Students should be familiar with positive and negative environmental impacts related to bioenergy production and sustainability, and evaluate inputs and outputs to make informed decisions. MEAN = 4.30 STANDARD DEVIATION = 0.92

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Environmental Impacts | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:

BIOMASS PRODUCTION Summary: Students should understand the methods involved with producing commercial quantities of biomass, including production costs and yields. MEAN = 3.85 STANDARD DEVIATION = 1.03

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Biomass Production | | | | | |

Explanation if your rating deviates one or more points from the mean:
Additional comments:
BIOMASS COMPOSITION Summary: Students should know the basic biomass components and recognize that the chemical composition of biomass impacts the quality of biomass products. MEAN = 3.87 STANDARD DEVIATION = 1.05

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Biomass Composition | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

CONVERSIONS Summary: Students should have scientific knowledge of converting biomass to intermediates and end products. MEAN = 3.83 STANDARD DEVIATION = 1.04

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Conversions | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

ENERGY BASICS Summary: Students should understand the fundamental principles of energy. MEAN = 4.43 STANDARD DEVIATION = 0.81

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Energy Basics | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

CURRENT TECHNOLOGIES Summary: Students should be familiar with current energy production, including fossil fuel and renewable energy technologies, and how they compare to bioenergy options. MEAN = 4.13 STANDARD DEVIATION = 0.72

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Current Technologies | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

POLICY Summary: Students should be familiar with existing and proposed policies that influence the growth of the industry, including Renewable Identification Numbers (RINs) and certification processes. MEAN = 4.26 STANDARD DEVIATION = 0.83

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Policy | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

BUSINESS-RELATED KNOWLEDGE Summary: Students should have a basic understanding of business management and strategy. MEAN = 3.78 STANDARD DEVIATION = 1.05

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Business-Related Knowledge | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

NON-BIOENERGY-SPECIFIC FUNDAMENTALS Summary: In addition to bioenergy-specific topics, students should also have fundamental coursework and skills (e.g. biology, chemistry, engineering, writing skills, data analysis, statistics, etc.) MEAN = 4.13 STANDARD DEVIATION = 1.02

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Non-Bioenergy Specific Fundamentals | | | | | |

Explanation if your rating deviates one or more points from the mean:

Additional comments:

BIOPRODUCTS Summary: Students should recognize the value of co-products in improving the overall economics and potential of bioenergy. MEAN = unavailable (not rated in Round 1)

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Bioproducts | | | | | |

Additional comments:

ETHICS Summary: Students should be aware of the moral principles involved to conduct themselves and guide technological development in an ethical manner.MEAN = unavailable (not rated in Round 1)

| | Non-essential (1) | (2) | Medium (3) | (4) | Essential (5) |
|---|---|---|---|---|---|
| Ethics | | | | | |

Additional comments:

With which of the following do you most closely identify?
Academia
Industry
Government
Other - Please describe: ____________________

If you have any additional general comments, please include them here:

# APPENDIX H

Minor Program Evaluation Survey

Consent Form:

This survey is being conducted in order to evaluate the Oregon State University Bioenergy minor program study, funded by the USDA. You are receiving this email because you are enrolled as a student in the above program. You must be 18 years of age or better to participate in this evaluation. We will be collecting information on you current progress in the program and a self-report of your knowledge and understanding of key bioenergy concepts. There is no penalty for choosing not to participate or for ending your participation early. While you are welcome to skip any questions that you do not wish to answer, any incomplete questionnaries will be discarded and the data will not be used. The evaluation should take about 15 minutes to complete. The risks to you as a participant are minimal, and include possible discomfort based on the questions being asked. Also, the security and confidentiality of information collected online cannot be guaranteed. Confidentiality will be kept to the extent permitted by the technology being used. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses. Once the survey is closed, if you have completed the survey your name will be added to a list that will be given to the SMILE program staff for dissemination of your $5 gift certificate. This person will not have access to any of your survey responses and your eligibility is based solely on completion, not on the responses provided. If you choose to end your participation in the survey early, you will not be eligible to receive a gift card. If you have any questions about your participation you may contact the principle investigator Darlene Russ-Eft at darlene.russeft@oregonstate.edu or (541) 737-9373. If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu.

I agree

I do not agree

1. Indicate which of the Bioenergy Minor courses below you have completed. Use the Bioenergy Minor course list if you are unsure of course numbers or elective classification.

BRR 350 Introduction to Regional Bioenergy

BRR 450 Interdisciplinary Research: Bioenergy Focus

WSE 473 Bioenergy and Environmental Impact

Elective: Technical (please indicate course below)

Elective: Environmental (please indicate course below)

Elective: Social/Economic/Policy (please indicate course below)

2. Please indicate your current major:
3. Please indicate your expected graduation date (mo/year):
4. Describe three strengths of the Bioenergy minor program.
5. Describe three areas needing improvement.
6. Anything else you would like to communicate at this point?
7. Please select the answer which best describes your situation. Use the Bioenergy Minor course list if you are unsure of course numbers or elective classification.

I have completed and/or are currently enrolled in courses for the Bioenergy Minor Program

I have not taken any courses in the Bioenergy Minor Program

8. Indicate your level of experience with participating in undergraduate research.

I have worked on a research project in the Bioenergy Minor Program

I have worked on a research project outside of the Bioenergy Program

I have not worked on any research projects

9. Please indicate your current academic level at Oregon State University.

Freshman

Sophomore

Junior

Senior
5th year Senior
Masters Student
PhD Student
Post Bac

10. What are your plans after graduation?

Enter the workforce
Apply to graduate school
Other (please describe below)

11. Learning Outcome 1: Demonstrate an understanding of the core concepts of bioenergy, present and discuss important contemporary issues and challenges related to bioenergy, and suggest multidisciplinary approaches to solving bioenergy problems. Please rate your competency with each of the following components of one of our program objectives. Please rate your current level of competency. If you have had no experience or knowledge with the component, please mark "0" with the slider (this is not automatic, if you do not click the slider at 0 you will not have a response recorded for the question).

Understanding of the core concepts of bioenergy
Ability to present important contemporary issues and challenges related to...
Ability to discuss important contemporary issues and challenges related to...
Ability to suggest multidisciplinary approaches to solving bioenergy problems...

12. Learning Outcome 2: Explain the research process, including quantitative and qualitative research methods and the use of evidence. Please rate your competency with each of the following components of one of our program objectives. Please rate your current level of competency. If you have had no experience or knowledge with the component, please mark "0" with the slider (this is not automatic, if you do not click the slider at 0 you will not have a response recorded for the question).

Ability to explain the research process
Understanding of qualitative research methods
Understanding of quantitative research methods
Ability to explain the use of evidence in the research process

13. Learning Outcome 3: Design a bioenergy research project, collect and analyze data, and interpret results. Please rate your competency with each of the following components of one of our program objectives. Please rate your current level of competency. If you have had no experience or knowledge with the component, please mark "0" with the slider (this is not automatic, if you do not click the slider at 0 you will not have a response recorded for the question).

Ability to design a bioenergy research project
Ability to collect data
Ability to analyze data
Ability to interpret results

14. Learning Outcome 4: Competently convey the meaning of research results in written and oral format, and demonstrate the ability to communicate with professionals, policymakers, and the general public. Please rate your competency with each of the following components of one of

our program objectives. Please rate your current level of competency. If you have had no experience or knowledge with the component, please mark "0" with the slider (this is not automatic, if you do not click the slider at 0 you will not have a response recorded for the question).

| |
|---|
| Ability to convey research results in written format |
| Ability to convey research results in oral format |
| Ability to communicate bioenergy with a variety of audiences |

15. What skills and knowledge have you gained by participating in undergraduate research?
16. What skills and knowledge do you hope to gain by participating in undergraduate research?
17. The Bioenergy Minor Program at Oregon State University was purposefully designed to be interdisciplinary, offering flexibility, access from a variety of fields, and utility, particularly with respect to the choice of electives. Please comment on what you feel are the benefits of the interdisciplinary nature of the minor program.
18. How important are the following aspects for your engagement, persistence, and overall involvement in the Bioenergy Minor Program? If you have had no experience or knowledge with the component, please mark "0" with the slider (this is not automatic, if you do not click the slider at 0 you will not have a response recorded for the question).

| |
|---|
| Interdisciplinary Program Aspects |
| Financial Support |
| Career Training/Prospects |
| Research Experience |
| Advising |
| Networking |
| Sustainability |
| Making a Difference in the World |
| Other (please describe below) |

19. Gender you identify with:

| |
|---|
| Male |
| Female |
| Transgender |
| Prefer not to answer |

20. Ethnicity (please check all that apply):

| |
|---|
| American Indian or Alaska Native |
| Asian |
| Black or African American |
| Native Hawaiian or Other Pacific Islander |
| Hispanic or Latino |
| White |
| Prefer not to answer |

21. Age:

| |
|---|
| 22 years old or younger |
| 23 - 25 years old |
| 26 - 30 years old |
| 31 - 35 years old |

36 - 40 years old
41 years old or older
Prefer not to answer

22. Are you a first generation college student?

Yes
No
Prefer not to answer

23. Please rate your current level of competence in each of the following skills.   If you have had no experience or knowledge with the component, please mark "0" with the slider (this is not automatic, if you do not click the slider at 0 you will not have a response recorded for the question).

Your ability to work with others
Your ability to work independently
Your ability to think critically
Your ability to discuss the ethical considerations of research

24. There are several skills that employers or graduate faculty look for beyond your course work known as “soft skills”.  Research experiences like the type that you receive through the Bioenergy minor help to provide these “soft skills”.  These skills aid you as you complete your work, such as being able to manage your time, set realistic work goals and timelines, and work in a professional environment. Please rate your current level of competence in the following skills. If you have had no experience or knowledge with the component, please mark "0" with the slider (this is not automatic, if you do not click the slider at 0 you will not have a response recorded for the question).

Time Management Skills
Organizational Skills
Self-Management Skills
Professionalism Skills
Decisions Making Skills
Problem Solving Skills

# APPENDIX I

Bioenergy Minor Program Graduates Interview Protocol

Consent Script: Interviews

This interview is being conducted in order to evaluate the Oregon State University Bioenergy minor program study, funded by the USDA. You are being interviewed because you completed the Bioenergy minor at Oregon State University.

Are you at least 18 years of age?

We will be collecting information about your perceptions of the program, as well as how the Bioenergy minor has been useful in your current work. There is no penalty for choosing not to participate or for ending your participation early. You are welcome to skip any questions that you do not wish to answer. The interview should take about 15-20 minutes to complete. The risks to you as a participant are minimal, and include possible discomfort based on the questions being asked. Also, the security and confidentiality of information stored digitally cannot be guaranteed. The interviews will be audio-recorded and transcribed. Confidentiality will be kept to the extent permitted by the technology being used. There are no direct gains for you based on your participation. If you have any questions about your participation you may contact the principle investigator. If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board.

Do you agree to participate in this interview and have our conversation recorded?

<u>Questions</u>

How has the Bioenergy minor been helpful to you?

What part of the program was the most beneficial to you?

Did you find the interdisciplinary nature of bioenergy well represented in the minor courses?

What are your thoughts, if any, on the interdisciplinary nature of the bioenergy minor?

Did you benefit from the research component of the bioenergy minor? If so, how?

What specific skills and knowledge, if any, did you gain from participating in the required research component of the bioenergy minor?

Are you using the skills and knowledge gained from your participation in the Bioenergy minor program? [Please explain]

Have you used what you learned from your bioenergy minor following your graduation?

Are you currently working in a field related to Bioenergy?

If so, describe your employment.

If not, why not?

Based on your professional experience, are there any suggestions for improvement you have for the Bioenergy minor program?

Is there anything else you would like to communicate with us about the Bioenergy minor program?

# APPENDIX J

BRR 350 Introduction to Regional Bioenergy (Modified Syllabus)

**2 credits**

**Instructors:** Bioenergy Instructor
Bioenergy Minor Director

**Time:** Wednesdays 6:00pm - 7:50pm. Two required Saturday field trips. This course combines approximately 60 hours of instruction, field trips, activities and assignments, for 2 credits.

**Prerequisites:** None.

**Introduction:** A strong regional bioenergy industry could revitalize agriculture and contribute to long-term environmental and economic sustainability. In addition, increased use of biofuels is an important step toward mitigating the climate impact of using fossil fuels, and directly serves the national goal of reducing US dependence on foreign oil. ***However, successful development of bioenergy will require that we integrate scientific, social, environmental, economic, and business- related competencies, to meet bioenergy goals while avoiding the pitfalls.*** This course, the first core class in OSU's Bioenergy Minor, will introduce Bioenergy core concepts and local Bioenergy industries and issues to an interdisciplinary audience.

**Course Description/Objectives:** Field trips to visit regional industry and research facilities will introduce Bioenergy core concepts and technologies. Guest lecturers will provide technical background and discuss economic, environmental and socio-cultural sustainability of Bioenergy. Course projects will analyze and present Bioenergy facilities and businesses in the context of regional Bioenergy issues.

**Learning Resources:**
BIOEN modules (http://fyi.uwex.edu/biotrainingcenter/)
Forest Bioenergy modules (http://learn.forestbioenergy.net/learning-modules)

**Learning Outcomes:**
After taking this course, students will be able to:

- Demonstrate an understanding of the core concepts of bioenergy, including feedstocks, conversion, and life cycle impacts.
- Present and discuss important contemporary issues relating to bioenergy.
- Effectively communicate bioenergy concepts.
- Explore and evaluate the role of bioenergy in regional research and industry.

**Evaluation of Student Performance:**

**Attendance and participation, including field trips**
**Turn in a question after 5 of the lectures**
**Reading, on-line quizzes**
**5 homework assignments**
**Course Project**

**Explanation of assignments:**
Turn in a question:

In class after lectures, each student will write a question to hand in about something in the lecture he or she doesn't understand or would like to know more about. Working in assigned teams, students will share their questions and participate in a group discussion.

Project:

Working in an assigned team, you will choose a Bioenergy business or facility (see list; only one team per company) and use it as the basis of a presentation, utilizing a presentation tool such as Powerpoint or Keynote. You will receive a detailed handout and in-class instruction.

**Field trips: Saturday field trips to Bioenergy facilities and businesses.** We highly recommend arriving at the facilities prepared with thoughtful questions. There will be a discussion in the vans returning from the field trip.

**Introduction to Bioenergy Minor and Requirements**

**Guest Lectures:**

**Introduction to Bioenergy**
**History of Bioenergy**
**Energy in Biomass**
**Grain Ethanol and Biodiesel**
**Feedstocks and Conversion**
**Life Cycle Analysis and Sustainability**
**Bioenergy, Policy and Regulations**
**The Business of Bioenergy**

**Group Presentations**

# APPENDIX K

BRR 450 Interdisciplinary Research: Bioenergy Focus (Modified Syllabus)

**2 credits**
**Instructors:** Bioenergy Instructor
Bioenergy Minor Director
**Time:** Wednesdays 6:00pm - 7:50pm. This course combines approximately 60 hours of instruction, activities and assignments, for 2 credits.

**Course Description:**
Bioenergy research presentations and papers introduce scientific inquiry, the research process, research seminars, papers and proposals. Analysis of different disciplines' approaches to research tools and data sources (e.g., quantitative versus qualitative approaches). Students write research proposals. Second core class in the Bioenergy Minor.

**Learning Resources:**
***Web based tutorial on Basic Research Concepts*****:** http://ori.dhhs.gov/education/products/sdsu/topics.htm
**Research Methods: The Practice of Science** *VisionLearning, National Science Foundation.*
http://www.visionlearning.com/library/module_viewer.php?mid=148

**Research Methods: Experimentation** *VisionLearning, National Science Foundation.*
http://www.visionlearning.com/library/module_viewer.php?mid=150

**Data: Uncertainty, Error, and Confidence** *VisionLearning, National Science Foundation.*
http://www.visionlearning.com/library/module_viewer.php?mid=157

**Grammar/writing help and tutorials** The Penguin Handbook Common Errors Workbook (http://wps.pearsoned.ca/ca_ab_faigley_penghdbk_1/64/16472/4217006.cw/index.html)

**Scientific Writing** *The ACS style guide: effective communication of scientific information, 3rd edition, 2006*.

**The Writing Center**

**Learning Outcomes:**
After taking this course, students will be able to:

- evaluate research talks, papers and studies, explain the issues addressed, discuss ethical considerations, and assess the conclusions.
- explain the research process, including quantitative and qualitative research methods and the use of evidence.
- describe key components of a research proposal.
- effectively use the library and writing resources on campus.
- suggest multidisciplinary approaches to solving bioenergy problems

**Evaluation of Outcomes:**
Three online quizzes based on reading
Library assignment
Recent developments in bioenergy: in-class presentation
Choose a topic
Submit slides
Presentation

Three In-class assignments
Two short papers on research presentations
Research Poster
Research Proposal
- Choose problem
- References
- Research proposal outline
- Proposal first draft
- Proposal final draft

**Extra Credit**: Use the Writing Center and/or Post references in the Reference Depot

**Library Assignment**: Attend an in-class presentation by a research librarian. Complete the assignment.

**Recent developments in bioenergy**: Select a research topic related to bioenergy, investigate in the current status of the research, and learn about the perspectives. Give a short (7 minute) in-class presentation explaining the topic to the class.

**Short papers on faculty research presentations**: Choose two of the faculty research presentations. Write a 2-page paper covering the background to the research, the rationale for the research and approach, important results, and the overall significance of the research. *Detailed assignment will be provided.*

**Research proposal**: Your will select an interesting topical Bioenergy problem or need, and the rest of the Research Proposal assignments will be based on this problem. We will suggest some possible topics to get you thinking, and you are free to use your own ideas. You will also be assigned to a group, which will provide you with feedback on your research proposal. Work with the other students in your group, try to pick their brains, and acknowledge their help in your work.

**Guest Lectures:**

Introduction to qualitative research: Professor, Sociology
How to ask and address a quantitative research question: Professor, Statistics
Energy: Professor, Engineering
Data Recording and Intellectual Properties: Associate, Research Office
Microbial Fuel Cells, Professor, Biological and Ecological Engineering
Scientific Integrity and Research Ethics

**Two Lab Tours**