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A Framework for K12 Bioenergy Engineering and Science Concepts: A Delphi Consensus Study

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An Engineering and Science Framework for Teaching K12 Bioenergy Concepts: A Delphi Consensus Study (Fundamental)

Challenge

Bioenergy is relatively unknown to the general public despite being the largest portion of all renewable energy sources in the United States. In 2013, biomass sources represented 50% of the total US renewable energy production of 9.2 Quadrillion BTU (US Energy Administration, 2013). By comparison, energy production from both wind and solar sources combined represented only 20% of the total US renewable energy production. Many other developed countries also have a well-developed bioenergy production system. However, these efforts toward using biomass as renewable energy receive very little publicity. Thirty percent (30%) percent of American adults were unable to name a single renewable energy source in a recent survey (Bittle, Rochkind, & Ott, 2009). In the same survey, only 5% of respondents named a biofuel as a renewable energy source. It is clear that in the United States, bioenergy and biofuels are not high in the public perception of alternative energy sources. Even in European countries, where biofuel use is relatively high, only 10% of the public could identify a biofuel used as a source of energy (Rohracher, Bogner, Späth, & Faber, 2004). It is evident that the public's knowledge of biofuels is very poor and in need of improvement. Without a basic knowledge of renewable energy sources such as bioenergy, it will be difficult to engage in a robust public dialog about the consequences of current energy usage and potential future solutions of these problems.

If the public has such a limited understanding of bioenergy, we would hope that K12 students would be better informed through learning activities in science classes. This does not appear to be the case. A recent study in New York State found that only 1% of middle school and high school students achieved a reasonable level of competency (correctly answering 80% or more) on a basic energy literacy test (DeWaters & Powers, 2011). While high school students did score better than middle school students, only one-third (35.5%) were able to correctly identify the definition of the term 'renewable energy source'. This poor understanding of basic energy concepts indicates that US students may need to learn more about renewable energy to be able to understand basic energy issues. A lack of energy literacy also applies to regions of the world were bioenergy is heavily used. In the heavily forested region of North Karelia, Finland, biomass sources account for 78% of all heating and electrical energy production (CO_2 Free Project, 2011). Even with biomass being the predominant energy source, students from this region still show poor knowledge of bioenergy. The majority of these students showed low bioenergy knowledge and were also critical of bioenergy in general (Halder, Pietarinen, Havu-Nuutinen, & Pelkonen, 2010). In other countries, students also show limited knowledge of biofuels as an energy source. Only 4% of students in a four-country survey (Finland, Slovakia, Taiwan, and Turkey) had high knowledge of bioenergy (Halder, Havu-Nuutinen, Pietarinen, & Pelkonen, 2011). Although no bioenergy-specific studies were located in a broad literature search of research in the

United States, it is reasonable to assume that American K12 students also have a poor understanding of biologically based energy sources. This general lack of youth knowledge about bioenergy will make it difficult for students to make informed decisions about alternative energy sources in the future.

In order to improve students' understanding of energy concepts, it is important that the topic is included in multiple classes and at multiple levels throughout their K12 experience. DeWaters and Powers (2011) argue that energy education should be interdisciplinary, integrating social sciences (history and geography) as well as the natural sciences (earth science, biology, chemistry, physics). The Next Generation Science Standards (NGSS) have attempted to address the lack of connections between disciplines with the concept of cross-cutting concepts (NGSS, 2013). The seven cross-cutting concepts propose concepts such as patterns, cause / effect, and energy / matter as a way to integrate disciplines. The NGSS argues that science curriculum should be developed to link concepts such as energy between the disciplinary content areas. A recent analysis of the Boston Public School 1-12 science curriculum showed that energy concepts are indeed fragmented into disciplinary silos (Chen, Scheff, Fields, Pelletier, & Faux, 2014). This means that students cover the same energy concepts in different classes, but learning does not necessarily build on prior knowledge and it is not connected to other content areas. Because current curricula do not do a sufficient job of integrating energy across the K12 science disciplines, additional work needs to be done to develop curriculum that covers multiple science disciplines, including biology, earth science, physical science, and chemistry. An ideal bioenergy curriculum would teach students core concepts of the field from the various disciplinary perspectives, as well as present the material in a learning progression appropriate for each grade band.

Discussion of a bioenergy curriculum leads to a question of what concepts would be essential to teach in a K-12 curriculum. Only a small number of researchers were located that have investigated appropriate methods and concepts to teach alternate energy. Research in Taiwan (Chen, Huang, & Liu, 2013) developed a list of ten energy concepts from literature that were deemed important to K-12 energy education. These dimensions included broad categories such as energy concepts, energy reasoning, low-carbon lifestyle, and civic responsibility. The researchers asked 28 experts in science education to rank the concepts for their importance in K-12 education. The experts ranked the low-carbon lifestyle and civic responsibility items higher than the energy concepts and reasoning. Of the three energy concepts included in the survey, understanding energy costs and benefits was ranked highest (5 out of 10). While this study did not elicit a comprehensive list of energy concepts from the experts, it identifies a potential direction for future research. In the United States the Department of Energy developed an energy literacy framework for use in K12 education. This framework (US DOE, 2012) outlines critical knowledge divided into 10 principles that K12 students should know about energy. The framework covers a broad range of energy concepts, but does not discuss specific types of biologically based renewable energy sources such as bioenergy. An exhaustive literature search has yielded no other recommendations for what K-12 students should be taught about bioenergy.

Given the importance of bioenergy to both global and US renewable energy production, it would be valuable to integrate these concepts into K-12 science education. Because traditional energy concepts have typically emphasized the physical science side of energy production (Chen, Scheff, Fields, Pelletier, & Faux, 2014), students only cover this material when the curriculum calls for physical science study. If the biological side of alternative energy production was included in energy education, students would receive a much more broad energy perspective. The goal of this research is to develop a consensus of bioenergy expert views on what K-12 students should be taught about bioenergy.

Theoretical Framework

Teaching bioenergy to K-12 students provides an opportunity to understand socio-scientific issues more deeply. Socio-scientific issues are unique in that they address the interaction and impacts between science and society. While a scientific issue might address whether oil well fracturing (fracking) produces long-term increases in oil production, the impacts of fracking on a community might be a socio-scientific issue. Bioenergy can be categorized as a socio-scientific issue because the motivations to pursue it are tied to larger societal issues such as petroleum depletion, oil independence, carbon dioxide levels, and climate change. In short, bioenergy may not yet be economically viable in some situations due to high costs of production, but might still be desirable from a socio-scientific standpoint because it may reduce carbon dioxide emissions or provide a way for a region to become energy independent.

Situated learning argues that students engage more deeply when the concepts they learn are embedded in social contexts. Sadler (2009) makes the case that engaging in classroom discourses on socio-scientific issues provides a context to situate science learning in the classroom. Rather than learning the science of biology, chemistry, and physics in isolation, bioenergy provides a real-to-life issue to relate concepts to. Situated learning (Lave & Wenger, 1991) places the learner in a community of practice that provides a context for knowing the background and practices of the community. Scientists and engineers do not work in isolation. Instead, a community of practice has developed that establishes cultural norms and expectations for the field. Situated learning makes the case that students must engage with this community of practice if they are able to appropriately use their knowledge in the correct cultural setting. Bioenergy provides a social context for learning science, engineering, and other disciplines. In addition, bioenergy allows students learning bioenergy to engage in multiple roles such as scientist, engineer, economist, and mathematician. Understanding science through the practices of these professions not only helps students to learn the concepts but it also situates the learning so that students leave the class knowing where to apply the information in a practical setting.

Teaching bioenergy to K-12 students not only prepares them for a larger discussion of climate change, it also has the potential to introduce them in the community that is charged with solving these problems. The challenges facing the world regarding energy production have not yet been resolved. Students can be engaged in proposing solutions that use alternative methods, such as bioenergy, to resolve energy issues facing their regions. The inclusion of engineering as well as science in this bioenergy framework allows students to take on the role of a bioenergy engineer or scientist who must

understand the larger issues and develop a technological solution to finding alternative energy sources. This moves students from developing arguments about energy issues to being an integral part of solving the problem. This approach situates the biology, chemistry, and physics concepts in a real-to-life context that allows students to better understand the issues.

Participants

Bioenergy experts were identified through their involvement in national bioenergy research and education initiatives. The US Department of Agriculture funded eight bioenergy research programs between 2011 and 2015 through the Agriculture and Food Research Initiative (AFRI). A list of researchers working on these projects was collated by contacting the principal investigator for each program. Invitation email letters were sent to 169 researchers with the request to forward to others they might recommend. Forty-two participants responded to the invitation and completed a questionnaire regarding their qualifications. Participants were considered eligible bioenergy experts if they met one or more of the following qualifications: Publication of at least one paper in a peer-reviewed bioenergy-related journal or two or more years teaching bioenergy classes at any level or a PhD in a related field. All respondents met the requirements for inclusion in the study. These respondents were randomly assigned to one of two study pools (K-12 or university). This study reports on the results of the K-12 participant pool. The results of the university study will be published separately. The final list of experts consisted of 21 participants with diverse backgrounds ranging from bioenergy university professors to researchers in spatial and transportation technologies.

Methods

This study was conducted using a mixed-method three-round "Classical Delphi" methodology (Okoli & Pawlowski, 2004). The Delphi method uses three features that distinguish it from other group techniques (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003): Anonymous group communication, multiple iterations, and statistical analysis of results. This approach was developed to integrate the views of a group of experts without some of the disadvantages of group meetings (Dalkey & Helmer, 1963). In a face-to-face setting, one individual can dominate the discussion or group thinking can lead to poor decisions. The Delphi approach attempts to encourage a consensus in a group by providing controlled feedback from a group of experts in an anonymous manner. The goal is to provide anonymous feedback on multiple iterations so that experts can evaluate the perspectives of all other members of the panel. Because the process involves paper or electronic surveys, it can be utilized with a panel of individuals that are separated geographically. For these reasons, it was chosen as the best method to develop a consensus on K-12 bioenergy concepts among a group of bioenergy experts.

The three rounds of this study consisted of a brainstorming round, a narrowing down round, and a ranking round. In each case, an electronic survey was developed using Qualtrics (Provo, UT) and an email was sent to each participant linking to the electronic survey. The Qualtrics tool allowed results from participants in earlier rounds to be integrated with the survey questions so that the experts could easily see other respondents' rationales and comments. Each round is described below:

Round 1 "Brainstorming". The goal of the initial round was to collect an exhaustive list of concepts from participants that was then sorted and rated in subsequent rounds. The survey consisted of two questions:

1) What core science concepts (if any) are essential for high school students to know about bioenergy by the time they graduate?
2) What core engineering concepts (if any) are essential for high school students to know about bioenergy by the time they graduate?

Respondents were allowed to respond with as many concepts as they desired. The final list of responses was open coded in Nvivo (Doncaster, Victoria, Australia) by two researchers for related bioenergy concepts until 100% inter-rater reliability was reached. The results of round 1 consisted of a comprehensive list of potential bioenergy concepts.

Round 2, "Narrowing Down" surveys were sent to all participants who completed the Round 1 survey. This survey presented the bioenergy concept themes that emerged from Round 1 analysis along with example participant responses. Participants were asked to rank each theme on a 5-point Likert-type item (1=non-essential to 5=essential). In addition, participants were encouraged to provide a justification or clarification for their answer. The mean and standard deviation were calculated for each item. In addition, justification and clarification responses were collated for use in the next round of the survey. Items that were rated 4.0 or higher (on the five point scale) by at least 2/3 of the participants were retained for round 3 (Osborne, 2001), and questions that did not meet this qualification were eliminated from the survey. The results of round 2 consisted of a shortened list of K-12 bioenergy concepts.

Round 3, "Rating" surveys were sent to the participants who completed the Round 2 survey. This survey consisted of the high-priority bioenergy concept themes rated in Round 2. In addition, any comments provided by participants in Round 2 were listed with each question. Participants were asked to provide any additional justifications or clarifications for each item. The mean and standard deviation were calculated for each item in the Round 3 survey. The result of round 3 were a shortened, prioritized list of K-12 bioenergy concepts.

Findings

Round 1 & 2

Of the 21 experts who agreed to participate in the study, 12 completed Round 1 and 9 completed Round 2. After coding Round 1 responses, eleven science themes and nine engineering concept themes emerged. The themes are listed below (See tables 1 and 2) along with the mean and standard deviation from participant rating in Round 2.

Table 1. Bioenergy science themes identified by experts for K12 education (N=12)

Theme	*Mean*	*Standard Deviation*
Climate change. Historical record and projected consequences	4.6	0.5
Energy fundamentals. Work, energy, conversions	4.5	0.5

Photosynthesis: How light energy is stored in plants	4.4	0.9
Chemical cycles: Water, carbon, nitrogen cycles	4.3	0.7
Ecosystems: Ecology and human impact	4.2	1.0
Conversion principles: Types of biomass conversions	4.2	0.8
Lifecycle assessment: Environmental impacts cradle to grave	4.2	0.9
Economics: How economics impacts biofuel use	3.9	1.1
Biomass sources: Sources of bio-based energy	3.8	1.1
Laws of thermodynamics: Conservation of energy	3.8	1.0
Public policy: Impacts of politics on bioenergy production	3.3	1.4

Note: Items ranked on a scale of 1= non-essential to 5=essential.

Table 2. Bioenergy engineering themes identified by experts for K12 education (N=12)

Theme	Mean	Standard Deviation
Energy consumption: Current and historical energy sources	4.8	0.7
Energy fundamentals: Types and conversions of energy	4.2	1.0
Energy requirements: Quantity and type of energy needed	4.2	1.1
Nature of engineering: Role of engineering in bioenergy	4.2	1.1
Conversion technologies: Conversion technologies	3.9	1.2
Bioenergy products: Type of biofuels	3.7	1.1
Lifecycle assessment: Social, environmental, economic impacts	3.7	1.1
Process economics: Economic analysis of conversion processes	3.4	1.0
Chemical engineering fundamentals: Conservation of mass/energy	3.3	1.5

Note: Items ranked on a scale of 1= non-essential to 5=essential.

Round 3

For the Round 3 survey, seven themes were removed from the survey due to their low ranking (below 4.0 mean). The remaining eleven items were rated 4 or higher by at least 2/3 of respondents in Round 2.

Table 3. Bioenergy engineering and science themes identified by experts for K12 education (N=8)

Theme	Field	Mean	Standard Deviation
Energy requirements: Quantity and type of energy needed	Engineering	4.88	0.35
Energy consumption: Current and historical energy sources	Engineering	4.88	0.35
Climate change: Historical record and projected consequences	Science	4.88	0.52
Nature of engineering: How engineering is important to bioenergy	Engineering	4.63	0.52
Energy fundamentals. Work, energy, conversions	Engineering	4.63	0.52

	/ Science		
Lifecycle assessment: Environmental impacts cradle to grave	Science	4.50	0.52
Photosynthesis: How light energy is stored in plants	Science	4.38	0.46
Conversion principles: Types of biomass conversions	Science	4.38	0.52
Chemical cycles: Water, carbon, nitrogen cycles	Science	4.25	0.35
Ecosystems: Ecology and human impact	Science	4.25	0.52

Note: Items ranked on a scale of 1= non-essential to 5=essential.

Contribution

Expert participants identified ten themes deemed essential to K12 bioenergy education. Of the top five themes, four were identified in the engineering field. This shows the relative importance the experts gave to engineering concepts in bioenergy education. Experts showed the most agreement on the top two themes, energy requirements and energy consumption. Both of these themes were rated 4.88 with a standard deviation of 0.35. This indicates the need to better help students understand the sources and quantity of energy demanded.

This research contributes to science and engineering teaching by providing guidance regarding which concepts are essential to K12 bioenergy education. Because bioenergy is a new field that is rapidly changing, it is difficult for educators to choose appropriate topics from among the many that are available. The bioenergy framework will provide a structure that STEM teachers can use to integrate aspects of divergent fields toward a common goal. It will also provide a baseline, which can be used to develop research instruments for understanding bioenergy learning. The goal is for students to develop an understanding of energy issues and potential solutions, including bioenergy. Bioenergy provides a way to situate science and engineering learning in a current socio-scientific challenge: Energy production. It is hoped that students learning about bioenergy will have a deeper understanding of energy issues facing the planet and be prepared to be a part of solving these issues in the future.

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