The Report Committee for Audrea H. Moyers
Certifies that this is the approved version of the following report:

Teaching Life Cycle Assessment Using Biofuels to Develop Process Thinking and Strengthen Core Science Understanding

APPROVED BY
SUPERVISING COMMITTEE:

Supervisor: ______________________________
David Allen

____
Richard Crawford

Teaching Life Cycle Assessment Using Biofuels to Develop Process Thinking and Strengthen Core Science Understanding

by

Audrea Haynes Moyers, BArch, BA

Report

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Dedication

This report is dedicated to my family, who have supported me throughout the process of pursuing my degree.

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I would like to acknowledge the support of everyone involved in the UTeach *Engineering* program. The faculty have been inspiring and motivating, the staff have been incredibly supportive, and my fellow students have been a source of knowledge and inspiration throughout. I am so glad that I joined this new program and was part of the first cohort—it has truly been a life-changing experience.

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Abstract

Teaching Life Cycle Assessment Using Biofuels to Develop Process Thinking and Strengthen Core Science Understanding

Audrea Haynes Moyers, M.A.

The University of Texas at Austin, 2011

Supervisor: David Allen

This action research project focuses on teaching life cycle assessment to engineering students in high school, using biofuels as a relevant application. The study examined the effectiveness of teaching methods related to both the engineering content—life cycle assessment—and the science content—biofuel production. It also examined underlying conceptions that students have about the preferability of some common consumer products from an environmental perspective, as well as their knowledge of ethanol compared to gasoline. The participants in the study consisted of sixteen college students enrolled in an Engineering Energy Systems course while pursuing either an undergraduate or graduate degree related to teaching engineering and science at the secondary level. The students participated in lessons written for a high school engineering science course currently under development in the UTeach Engineering program at The

University of Texas at Austin. Data were collected from a pre- and post-unit assessment, observation of student activities and behaviors, and a participant survey. The results of the study suggest that student understanding of the environmental implications of products or processes is deeper after completion of the unit. The study also shows a positive relationship between hands-on sense-building activities and student engagement. As an action research project, the primary goal is the immediate improvement of teaching to increase learning in the classroom. Modifications to the unit and lesson design have been made based on the results of the study in preparation for using the unit with high school students in the following school year.

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Chapter 1: INTRODUCTION

Educational research, as well as personal teaching experience, indicates that students at all levels struggle with making high-level connections between concepts, particularly in this age of high-stakes standardized testing and content-stuffed standards. Students need repeated exposure to concepts and varied opportunities to structure, and restructure, their knowledge to fundamentally embed understanding (Bransford, Brown, & Cocking, 2000). It is not enough to introduce content that students can recall in the short term on an assessment if they cannot apply their knowledge to new situations in the long term. The high school system that breaks science instruction down into discrete subjects that rarely overlap does not help students make these high-level connections. Students struggle with knowledge retention, an inadequate grasp of concepts, and problems applying principles to new situations. This knowledge transfer both within and between science courses is critically important for student learning and long-term understanding (Bransford, 2000).

Up until ninth grade, science instruction in Texas spirals through key subjects from different science disciplines, ideally covering topics in greater depth at higher levels. An examination of the Texas Essential Knowledge and Skills (TEKS) standards shows that from Kindergarten through eighth grade, all science covers the same core areas: scientific investigation and reasoning; matter and energy; force, motion, and energy; earth and space; and organisms and environment (Texas Administrative Code (TAC), 2011). At the high school level, however, science instruction is highly compartmentalized into three core courses—biology, chemistry, and physics—which are taught without much overlap. This strategy makes sense to address the amount of content in each discipline that needs to be taught, but it does not help students make connections between disciplines which are inherently interconnected in the real world.

A class like environmental science or engineering science provides a valuable opportunity for high school students to make these interdisciplinary connections. The challenge becomes getting students to think about combining their separate areas of knowledge. I have heard students proclaim, "But, that's chemistry!" when asked to determine the molecular mass of a compound when calculating the emission rate of an air pollutant as part of an engineering design challenge where air quality is a factor. Somehow, in students' minds, chemistry is a field of science that should stand in isolation and has no relevance in an engineering science course. I do not get the same response when asking students to use their physics knowledge—perhaps because it is a more recent course, but perhaps because of student perceptions of what engineering entails (primarily mechanical engineering).

A curriculum for Texas' Engineering Design and Problem Solving (EDPS) course, which counts as a fourth science credit, is being written and field tested by the UTeach Engineering program at The University of Texas at Austin. A central goal for this course is to teach science through the lens of engineering design. As engineering design covers the full range of science applications, the course has the potential to be truly interdisciplinary with respect to science fields. The TEKS for this course are very open-ended in relation to what science concepts are taught, leaving the course developers a lot of difficult choices as to what to include or exclude. The following standard is the only one to directly address science content in the course: "(2) The student is expected to: (A) apply scientific processes and concepts outlined in the biology, chemistry, or physics TEKS relevant to engineering design problems." A stated goal in the TEKS is that the course "reinforces and integrates skills learned in previous mathematics and science courses" with an emphasis on "solving problems—moving from well-defined toward more open-ended—with real world application" (TAC, 2011).

One real-world application of engineering design is teaching about design for sustainability. Students in the 21st century are vividly aware of issues related to sustainability and environmental concerns. However, when asked to discuss specific concepts related to environmental science and sustainability, many students rely on anecdotal information and cannot describe the science concepts that form the foundation of their personal preferences and beliefs. There is a pervasive lack of awareness of the processes necessary to fully understand some of these complex issues, such as choosing between alternative fuel options or evaluating "green" products. This is not surprising considering the complexity of the issues and the lack of a forum in most high school classes to address this concern. Including a unit on sustainability in the EDPS course will allow students to explore a relevant and timely application of engineering design.

When discussing sustainability, it is not enough to address specific product choices in isolation, such as choosing between two types of alternative fuel vehicles. Technology is constantly changing, and new solutions to engineering challenges are continually being developed. Teaching students a process with which to evaluate complex sustainability decisions would provide them a valuable tool for future use as citizens, consumers, and designers. It would also broaden their understanding of engineering design to include process engineering, which forms the core of disciplines such as chemical and petroleum engineering. For this reason, Life Cycle Assessment (LCA), which examines the entire life cycle of a product or process to evaluate its environmental impacts, is an ideal engineering process to integrate into the curriculum.

When considering what specific examples of products or processes to use for a life cycle model, there are many to choose from, particularly consumer products that most high school students will have some direct experience with. Well-known LCA studies exist for products such as grocery bags, diapering systems, fast food packaging, beverage containers, and many more. Evaluating these types of examples would give students real-world applications of the LCA model and how it can be applied to choices they make daily. However, these product examples might not provide a strong opportunity for reinforcing core science concepts.

Recent legislation mandates the use of life cycle evaluation for alternative fuels. The 2007 Energy Security and Independence Act requires government agencies procuring alternate fuels to show that life cycle greenhouse gas emissions of these fuels are better than or equal to petroleum (as cited in Aviation Fuel Life Cycle Assessment Working Group (AFLCAWG), 2009). Focusing on biofuels as a specific application of the LCA process provides a relevant example of how this process is used in industry and relates to government policy. In order to understand the life cycles of biofuels, students will need to explore the biochemistry that is the foundation of their production and use. Studying the LCA process through biofuels provides an opportunity to deepen core science knowledge while studying a timely engineering design model.

The goal of this action research project was to design and implement an active-learning based instructional unit on the Life Cycle Assessment process using biofuels and evaluate that unit of instruction. To do this, it was necessary to take a three-pronged research approach and explore:

1. educational research on increasing student understanding, particularly with respect to science concepts,
2. the fundamentals of Life Cycle Assessment and biofuels from a content standpoint, and
3. existing curricula related to Life Cycle Assessment and biofuels.

Chapter 2: REVIEW OF LITERATURE

2.1 – Educational Theory: Increasing Student Understanding

A great deal of attention is being paid, nationwide, to Science, Technology, Engineering, and Mathematics (STEM) education as a vital component of our continued national success in innovation and industry. In the last decade, countless grants have been created and programs initiated for all levels of education to encourage students to engage in STEM lessons, courses, clubs, and competitions with varied goals including strengthening science and mathematics understanding, adding engineering design to secondary curricula, and increasing the numbers of engineering majors in college. Concurrently, more emphasis has been placed on instructional strategies for teaching STEM content, particularly science. I have observed in my 11 years of teaching an increased focus on active learning, project-based learning, and formative assessment for science.

Due to this increased focus on science teaching and learning, it is possible to find a variety of excellent research to guide teachers who seek to improve their practice. Research has shown that "knowledge taught in a variety of contexts is more likely to support flexible transfer than knowledge taught in a single context" (Bransford, 2000). This argues for the benefits of a course like engineering science, where prior science concepts are reintroduced and utilized for problem-solving related to design challenges. I have experienced first-hand the trouble many students have with applying mathematics and science concepts to engineering problems. They tend to compartmentalize mathematics skills and science concepts and need explicit prompts to apply them in a new context. A goal for the engineering science course is to motivate students to think about science as more than terms and equations relevant to a particular unit with clear boundaries. Well-designed engineering projects can help students see how science concepts and engineering practices affect their daily lives, choices they will have to make as adults, and potential career activities and opportunities.

A major goal of any instruction should be the flexible transfer of knowledge to new situations. This goal puts pressure on teachers to move beyond lecture-based lessons with student note-taking that encourage short-term memory use but do not encourage flexible transfer or long-term understanding. The National Research Council published *How People Learn: Brain, Mind, Experience, and School*, which has become an influential synthesis of educational research. The authors point out that many instructional strategies appear equal when evaluated on how well students can memorize facts, but "instructional differences become apparent when evaluated from the perspective of how well the learning transfers to new problems and settings" (Bransford, 2000). When developing instructional units, it is necessary to seek and implement strategies that encourage knowledge transfer.

What instructional strategies make flexible transfer of knowledge more likely to occur? An underlying theme is the idea that students need to confront their own conceptions and misconceptions about a subject before being given learning opportunities. This idea stems from constructivist educational theory, and a learning environment that promotes this is called a Learner-Centered Environment (Bransford, 2000). In order to restructure their thinking about a topic, students first need to address their current thinking. Once they are given engaging opportunities to form new understandings they must then reflect on the changes in their own learning that have occurred. This conceptual reorganization is critical in science, as many students have formed ideas about how the world "works" based on personal experience and observation, and these ideas are often either incorrect or incomplete. They are also pervasive and difficult for teachers to truly change. Students might memorize relevant facts regarding a topic without truly reordering their conceptual understanding to include new knowledge (Bransford, 2000). This tendency argues for more effective ways to teach science to ensure deep understanding and a correct foundation of knowledge.

When applied to unit and lesson design for sustainability, current science learning research indicates that teachers must provide students opportunities to discuss their current understandings of sustainability before expanding their conceptual understandings by introducing techniques such as life cycle assessment. Today's young people hear many conflicting views on the environment, human practices that affect it, and specific products they encounter—from their classes in school, their families, and a variety of media. They must be given activities that support them as they confront their current ideas and learn new ideas that can be applied in novel situations. "By probing students' beliefs and helping them develop ways to resolve conflicting views, teachers can guide students to construct coherent and broad understandings of scientific concepts" (Bransford, 2000). The teacher has an indispensible role in knowledge construction and needs tools for "probing student beliefs" that must be integrated into lesson design.

A research-proven technique for eliciting student prior knowledge is the use of formative assessment tools. Formative assessments are a "way to elicit the prior ideas students bring to the classroom, making their thinking visible to themselves, their peers, and the teacher" (Keeley, 2008). Not only does the teacher need to know what ideas students have about a subject, but students need to see their own ideas and those of their peers as a starting point. This can also encourage discussion, which can lead to further questions students have and need to answer to solve conflicts between their ideas, those of their peers, and the information presented by the instructor or learned through activities.

A successful teacher must use a variety of formative assessment tools to help "design targeted instruction and create conditions for learning that take into account and build upon students' preconceived ideas" (Keeley, 2008). Some formative assessments are best used at the beginning of a lesson to elicit prior knowledge while others assist with sense-making during a lesson activity. A learning environment with integrated formative assessments used for feedback and revision is known as an Assessment-Centered Environment and is one of the four aspects of learning environments necessary for successful student learning to occur (Bransford, 2000).

Research has been conducted into student misconceptions in various fields of study, including science. It is important for teachers to understand the prior knowledge—both correct and misconceived—which students bring to the classroom. Misconceptions are not completely useless thinking that must be eradicated for true learning to occur. Rather, misconceptions represent the "mapping of a working idea in a plausible but incorrect way" (Wiggins & McTighe, 2005). They are actually evidence that students have attempted knowledge transfer. A teacher must confront, and help students to confront, misconceptions in order for knowledge presented to be correctly structured for future use in novel problems.

A specific examination of student misconceptions related to photosynthesis reveals that students at all levels struggle to explain some of the very basic processes related to the carbon cycle—such as where the mass of a plant comes from (Koba & Tweed, 2009). Since the biofuels lessons require applying the carbon cycle to the processes of photosynthesis, fermentation, and combustion, it is critical to address any misconceptions related to energy and matter transformations. Photosynthesis can be considered the foundation process on which students can build their understandings about flows of energy and cycling of matter (Koba, 2009). One promising practice is the use of a technique such as a concept cartoon to quickly elicit student responses regarding a key concept. The concept cartoon presents a question at the core of science understanding and gives students several choices, including the most common misconceptions identified in research. At the very least, responses to the cartoon give the teacher quick insight into student thinking on a topic. If students are asked to discuss with peers and formulate a shared group response, then students also have to confront their own thinking and explain it to peers in order to reach a consensus (Koba, 2009). The concept cartoon can be revisited at the end of the lesson as well, to provide an opportunity to reflect on any changes in understanding instigated by the lesson. The concept cartoon is one example of a formative assessment incorporated into the unit design. Table 1 lists other formative assessment techniques used in the unit as well as the rationale for their use.

Strategy	Rationale
pre-unit assessment	gauge student conceptions and misconceptions; discuss results with class to form basis for restructuring understandings
opinion continuum	students can visualize class distribution of opinion and have opportunity to discuss rationale with others; when repeated at end of lesson, students can visualize changes in opinion
annotated sketches	students use prior knowledge to diagram a concept and identify Need To Know areas
concept cartoon	uncover student preconceptions in concise format, allow for student discussions of preconceptions in small groups; revisit at end to note changes in thinking
process diagramming	diagram creation scaffolded (with images) to explore life cycle concepts in small groups, identify Need To Know concepts
3-2-1- summarizer (3 facts, 2 interpretations, 1 connection)	help students make connections about lesson concepts; teacher can gauge student understandings
editorial cartoon discussion	engagement activity to address public perceptions and debates related to biofuels; can generate questions for further study
quick write	concise reflection on a prompt related to the lesson activities to spur making connections
entry ticket for homework (one-page background readings)	entry-ticket for quick assessment, spur to discussion, and accountability to support short readings that structure classroom activities
image comparison and reflection	written assessment of contradictory biofuel imagery (pro and con) to encourage students to apply knowledge to media representations of science and technology innovations
post-unit assessment	gauge student understandings at the end of the unit and gauge changes in understandings as a result of the unit

Table 1: Formative Assessment Strategies Used

In addition to learner-centered and assessment-centered, successful learning environments should also be knowledge-centered. New information must be organized around core concepts and presented in a logical sequence in order to encourage students to form structured thinking around a topic (Bransford, 2000). This goal is consistent with "backward" curriculum design, which begins with careful consideration of big ideas and enduring understandings before specific lesson activities are created. A unit planning template based on the work of Wiggins and McTighe was employed to facilitate this process and "reinforce the appropriate habits of mind needed to complete designs for student understanding" (Wiggins, 2005). Consideration was given to enduring understandings related to both engineering and science as a starting point for design. The unit design document is included in Appendix A.

A final aspect of successful learning environments identified in *How People Learn* is the creation of a community-centered environment. A community-centered environment is one in which students feel comfortable taking academic risks and where opportunities are provided for students to confront their own ideas and those of their peers, obtain feedback, and revise their thinking (Bransford, 2000). The classroom is a community where students work together in different configurations to solve problems, often building on each other's knowledge to advance group learning. The use of embedded formative assessments—not just for teacher knowledge but for student knowledge of their own thinking—greatly assists in creating this type of environment, where students are comfortable confronting their own ideas and those of their peers and working together to form new understandings. The lessons were designed to encourage students to work in various types of group formations for different durations and consistently discuss their thinking in all aspects of work.

2.2 – Lesson Content: Life Cycle Assessment

In order to design the unit of instruction around Life Cycle Assessment, it was necessary to investigate current research in the field in order to present an accurate view to students. Information about LCA is readily available for both teacher background information and student use. Articles vary from brief overviews to highly detailed reports of products, but LCA is not commonly included in standard engineering textbooks. A central question throughout the unit and lesson design was how to work with LCA in a meaningful way with high school students in a relatively short unit of instruction without getting bogged down in excessive detail. Core LCA concepts to include in an introductory unit are: (1) the stages of a product's life cycle, (2) the four steps of a Life Cycle Assessment [scope and boundaries, Life Cycle Inventory, Life Cycle Impact Assessment, and Life Cycle Improvement Analysis], and (3) the concepts of the system boundary and the functional unit (Rosselot & Allen, 2000).

Students are asked to consider the life cycle of a popular consumer product, an athletic shoe, and diagram its life cycle as a starting point to explore their understandings of the concept. Once they have documented their own ideas about what a product's life cycle might be, they are introduced to several diagrams in a class discussion and have the opportunity to compare their initial ideas to those used in industry for life cycle assessment.

Research has shown that abstract processes, like photosynthesis or life cycle assessment, are difficult for students to grasp. When they are not given opportunities to visualize or experience these abstract processes first-hand, they are more likely to rely on short-term memory in a classroom setting and fall back on prior notions once a unit is complete (Keeley, 2008). For beginning students, core

LCA concepts are best made concrete using examples from everyday life. As mentioned previously, LCA studies have been completed for a variety of consumer products including grocery bags, soda beverage containers, diapering systems, fast food packaging, desktop computers, and more. The paper vs. plastic grocery bag question was chosen because most students will have been exposed to the choice at most grocery stores, or at least be aware of what their own family uses. In addition, accessible Life Cycle Inventory (LCI) data is available for students to use, as well as a well-developed problem set (Allen, Bakshani, & Rosselot, 1992). The lesson begins with an Opinion Continuum formative assessment activity to allow students to visualize their own and their peers' opinions on which grocery bag is better for the environment and record some early ideas about why they think this way. The primary activity of the same lesson is to quantitatively evaluate data from an LCI of the two types of bags in order to approach the question from a more holistic life cycle viewpoint with supporting data. At the end of the lesson they revisit the opening question and activity with an opportunity to discuss the results of the activity, the LCA model used, and any changes to their own understandings of a product's environmental "footprint."

2.3 – Lesson Content: Biofuels

To frame the use of LCA for students, and the importance of studying it as a pertinent, timely practice, it was necessary to research current US policy. Completing LCAs is not required in most industries, but due to federal and state legislation, transportation fuel has become an exception. As mentioned previously, one example of LCA in the regulations is the EISA of 2007, which placed a requirement on government agencies to show that a proposed alternative fuel has a life cycle greenhouse gas (GHG) emission less than or equal to conventional petroleum made from conventional sources (AFLCAWG, 2009). For this reason, and because of other, related legislation, research has focused on the LCA of conventional fuels to create a petroleum baseline and alternative fuels as a comparison.

In order to use biofuels as a case study for the LCA process, it was necessary to investigate current research in biofuel production. There is abundant information at all levels related to this topic, from K-12 lessons to government reports. To frame the discussion for students and answer the important "why do we need to study this" question, information from government agencies and current regulations was particularly valuable. Under the EISA of 2007, the existing Renewable Fuel Standards (RFS) were expanded to require an increased volume of renewable fuel to be blended into transportation fuels—from 9 billion gallons in 2008 to 36 billion gallons by 2022 (EPA, 2010).

For the purposes of writing this unit of instruction, emphasis was placed on the stages of biofuel production and the biochemistry of ethanol production, as the lessons focus on tracing matter and energy through a fuel production system. Students explore different types of ethanol feedstocks to make cellulosic ethanol, and the U.S. Department of Energy report *Breaking the Biological Barriers to Cellulosic Ethanol* (U.S. DOE, 2006) was valuable in framing the issues that we face for increasing our utilization of this type of transportation fuel as well as explaining the processes used in its creation. Information from this report went into making the lesson content, particularly the presentations made for class use and homework background reading.

2.4 – Existing Curricula

While hundreds of articles have been written about the LCA of biofuels, very few address teaching LCA in general and biofuel LCA in particular. Similarly, many lessons exist related to biofuels, but few published lessons relate to biofuel LCA. The few articles on teaching LCA relate to university students and address general strategies used, such as case studies and product comparisons (Cooper & Fava, 2000). The need for teaching process thinking in general, and life cycle assessment in particular, has huge research potential.

A few instructional units related to LCA were very valuable in shaping my own unit design. *The Life Cycle of Everyday Stuff* is a published science curriculum which allows students to explore the life cycles of common consumer items (Reeske & Ireton, 2001). I taught much of this curriculum several years ago in an introductory engineering design course, and found it to be a good starting point for addressing concepts not covered in core academic courses, such as raw materials, manufacturing, and product design. I felt it to be lacking in appropriate formative assessments, however, particularly when it came to eliciting student prior knowledge. The biggest challenge students faced throughout the unit was a lack of knowledge and understanding about materials, even very common materials such as plastic, sources of energy, and energy transformations. While I did not use any activities from this unit directly, my experience teaching it and observing student responses shaped many of my views about what a unit on LCA should contain and how content should be presented to students for increased engagement and understanding.

The Ford Partnership for Advanced Studies (Ford PAS) has published extensive online curricula, available free to schools, for interdisciplinary courses related to engineering, business, and technology. The material includes a unit on *Closing The Environmental Loop* which focuses on the design and business aspects of Life Cycle Thinking. It includes activities and background information related to materials and manufacturing, recycling and environmental impacts, the impacts and processes of businesses, and a culminating design project (Ford PAS, 2003). The interdisciplinary nature of the curriculum makes it ideal for a technology or business course and a good starting point for economics, social studies, or science. However, the science content is minimal and general, and so is not appropriate to the goals of my unit design. I used the idea of telling the "life story" of an athletic shoe, which is an early activity, as I have found that high school students of both genders are very interested in athletic shoes and they represent an item both common and mysterious (in relation to how they are made and where their materials come from).

Dr. David Allen, who teaches a freshman "signature" course on sustainability at The University of Texas at Austin, has a web-based tutorial (Allen, 2000) on LCA to evaluate products' environmental footprints. The background reading (Rosselot & Allen, 2000) was crucial to developing my own understanding of the LCA process and helping me to differentiate between what information was necessary to include in a unit for high school students and what information was interesting but beyond the scope of my work. The tutorial includes a set of problems, and I based the paper vs. plastic problem set for my LCA lesson on the one included in the tutorial.

Many lessons and study guides have been published and are readily available online concerning energy in general and biofuels and ethanol in particular. Most of these provide good, concise background information on types of fuels; some provide activity guidelines or worksheets based on the written information. For example, the National Energy Education Development Project (NEED) has an extensive online library of energy curriculum guides (NEED, 2008). The Ethanol guide includes summaries, written at three grade level ranges, of ethanol information, an "ethanol math" activity which at the secondary level is about graphing emissions, a crossword puzzle for each level, and a list of suggested activities including research, presentations, and a brochure. While these types of resources can be excellent supplemental information for a teacher, they are not written as a comprehensive unit and most lack the instructional strategies discussed in this paper as being most beneficial to student learning.

One existing unit and lesson design related to both life cycle thinking and biofuels has been very influential on my own unit and lesson design. The Great Lakes Bioenergy Research Center has an online unit called *Life Cycle Assessment of Biofuels 101*. One of the fundamental activities in the unit, a "walkthrough" where students trace carbon and energy through the production of ethanol, was described in an article and inspired my own use of the technique to work with students to understand the matter and energy transformation that occur (Krauskopf, 2010). This unit was written for a science course, using many of the instructional strategies discussed earlier in this report, particularly eliciting prior knowledge. It focuses on biofuels within a shell of life cycle assessment, using LCA as a tool to help students understand the transformations of matter and energy necessary to produce and use ethanol. I have modified and used the walkthrough and spreadsheet activities from this unit in my lessons. For a unit for engineering design students it was necessary to add information on the LCA process so that it was a subject in its own right, rather than merely a tool to promote science learning. Focusing on the LCA process and key decisions like system boundaries and functional unit before discussing biofuel specifics helps students understand the tradeoffs present in the spreadsheet models used in later lessons to evaluate alternative biomass feedstocks.

Chapter 3: METHODS

Once the unit and lesson design were complete, consideration was given to how best to evaluate the results. Research in engineering education is a relatively new field and much attention has been given to quantitative, qualitative, and mixed method research methodologies, which fit well with engineering disciplines. Other research models exist, although they have not been extensively applied to engineering education research (Case & Light, 2011). One methodology that seemed particularly appropriate for this work is the action research model (McMillan, 2008).

I chose the action research model as the most relevant way to develop and refine a curricular unit. Educational action research is a systematic investigation, conducted by a practicing teacher, into teaching strategies and content development to immediately improve teaching and student learning. The central goal is to gather evidence to make informed, rather than intuitive, decisions about teaching and learning in a classroom environment (McMillan, 2008). As shown in Figure 1, action research relies upon three types of information: observations of student work process and behaviors, analysis of student work products, and analysis of student surveys and/or interviews. Unlike traditional research, action research has a local, specific focus—although results can often be extracted that can apply to other learning situations.

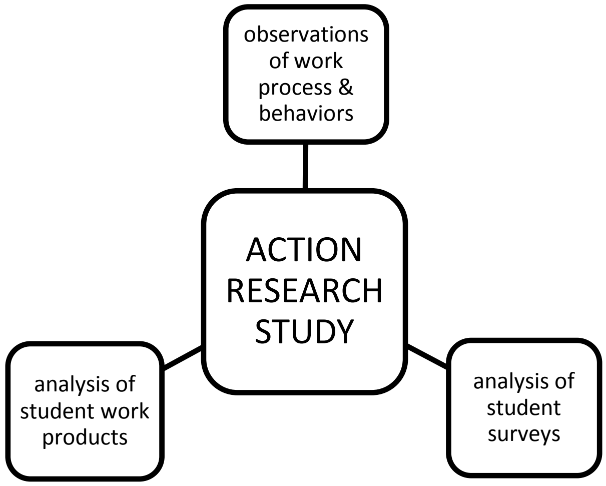

Figure 1: Action Research Model

The focus of my action research was the creation and implementation of a two-week unit of study. The unit design included an engineering focus on life cycle assessment and a science focus on the creation of biofuels. To create the unit, I used a backwards-planning approach (Wiggins, 2005) to "begin with the end in mind." I established my essential questions and enduring understandings with help from the TEKS for my course (TAC, 2011) and adult science literacy standards (AAAS, 2011). I modified existing lesson activities from a variety of sources mentioned previously. I crafted lessons around these activities using teaching guidelines and strategies discussed earlier in this report, with the intent of creating active-learning lessons that give students opportunities to construct their own understandings of both process thinking and the biochemistry of transportation fuels. A unit plan and set of 5 90-min lessons were created. The unit design planning document is included as Appendix A. The complete set of five lesson plans is included as Appendix B.

Once the unit design and lesson content were complete—including presentations, worksheets, handouts, and activity files—I needed to implement the unit in order to gain feedback on a variety of factors, including the effectiveness of teaching strategies, difficult concepts for students to grasp, and the timing of the lessons as a whole and individual activities within the lessons. The participants in the focus group consisted of sixteen college students enrolled in an Engineering Energy Systems course while pursuing either an undergraduate or graduate degree related to teaching engineering and science at the secondary level. The majority of participants in my focus group were experienced teachers in STEM areas. For this reason, the research also included a survey to gauge the success of lesson activities and teaching techniques. While any student can be asked for his or her opinion on activities and strategies employed by the instructor, practicing teachers can provide valuable insight as both students of the lessons and teachers who might teach similar content.

For the focus group, two 3-hour sessions were used to implement the lessons. A content-specific pre-unit assessment was administered to the focus group before the unit began. Three lessons were completed and two final lessons were outlined and discussed. A post-unit assessment was administered to gauge changes in student understandings of concepts presented, discussed, and demonstrated in the lessons. Finally, a survey related to lesson activities and instructional strategies was administered to the focus group to gain insight into participants' perceptions of the various activities and their relative success in providing engaging, relevant, and rigorous content. These instruments asked for open-ended written responses to the activities completed and instructional strategies used.

Chapter 4: RESULTS AND DATA ANALYSIS

4.1 – Pre- and Post-Unit Assessment Comparison

The pre-unit assessment was analyzed for the following elements: general trends related to student preconceptions about the environmental impacts of consumer products, particularly grocery bags; understandings of the biofuel ethanol when compared to gasoline; and abilities to produce a diagram of the life cycle of a consumer product. Analysis of the post-unit assessment focused on comparing overall student responses to the pre-unit assessment to determine changes in understanding after completion of the lessons.

The table below shows the responses on both the pre- and post-unit assessments to the initial question, "Which is better for the environment—paper or plastic bags?" This question is deliberately vague, with room for written rationale, in order to elicit a broad range of responses. Several participants gave more than one reason for their answer.

Which is better for the environment: paper or plastic grocery bags?				
	Pre-unit		Post-unit	
Paper	7	47%	4	25%
Plastic	7	47%	10	63%
Depends on the recycle rate	0	0%	2	13%
Equal	1	7%	0	0%
Why? (answers could be written in)				
	Pre-unit		Post-unit	
Is biodegradable	4	19%	3	14%
Can be recycled	8	38%	0	0%
Does not kill trees	3	14%	0	0%
Trees are renewable	3	14%	2	9%
Less energy is needed	3	14%	12	55%
Fewer emissions are created	0	0%	5	23%

Table 2: Pre- and Post-Unit Assessment Results, question 1

The data collected show that completion of the unit does make students consider different aspects of the life cycle of a product when considering its environmental impacts. In the pre-unit assessment, the group was evenly split between favoring paper or plastic bags as a better environmental choice. The majority of students, 57%, said that their product was better for the environment based on the ability to recycle it or that it could decompose easily. This response, focused on the end-of-life stage of a product, is consistent with my observations of high school students when considering common consumer items—recyclability and decomposition in landfills are the most common reasons cited for a product to be good for the environment. In the post-unit assessment the group was still divided as to whether paper or plastic bags were more environmentally friendly, but 55% cited less energy used as their primary consideration. While no one mentioned emissions as a concern before the unit, 23% gave lessened emissions as a reason for their answer after completing the lessons.

The life cycle inventory data used in the first lesson focused on energy use and emissions for the two types of grocery bags at three different recycle rates. It did not include other impact categories, such as water use or landfill space, nor did it include factors such as re-use of a bag before disposal. Once the calculations and graphing of results were complete, students could see that plastic bags are superior with respect to greenhouse gas emissions, regardless of the recycle rate of the bags, and paper bags are only more energy efficient at very high recycle rates, above 90%. Based on their responses, the students seemed very aware of the limitations of the model, and some qualified their answers. One student wrote: "Apparently plastic [is better], according to our model. But of course the model isn't all-inclusive. Actually, the model we used focused mostly on energy, not necessarily 'ecofriendliness.' I still have a gut feeling that plastic is worse." A more in-depth model, with more inclusive inventory data, would be necessary to help this student move from a "gut feeling" to a data-supported opinion. Regardless, acknowledging the limitations of an engineering model represents an important conceptual milestone.

4.2 – Life Cycle Diagram Comparison

As the final question on the pre- and post-unit assessment, students were asked to draw a diagram "that represents your current understanding of the life cycle of a consumer product, such as a car." As with the grocery bag question, the wording was intentionally general to elicit a variety of student responses. All but two of the sixteen initial diagrams included stages before the "use" stage of a product; these are labeled with such titles as raw materials, production, or manufacturing. This is not consistent with my experience working with high school students in this topic. Before learning about life cycle assessment, most of them begin a diagram with the use stage of a product. All sixteen final diagrams did include stages before "use," although there was great variation in the exact stages represented and how they were labeled. Figure 2 is a diagram on the pre-unit assessment that includes both an awareness of material processing and energy requirements.

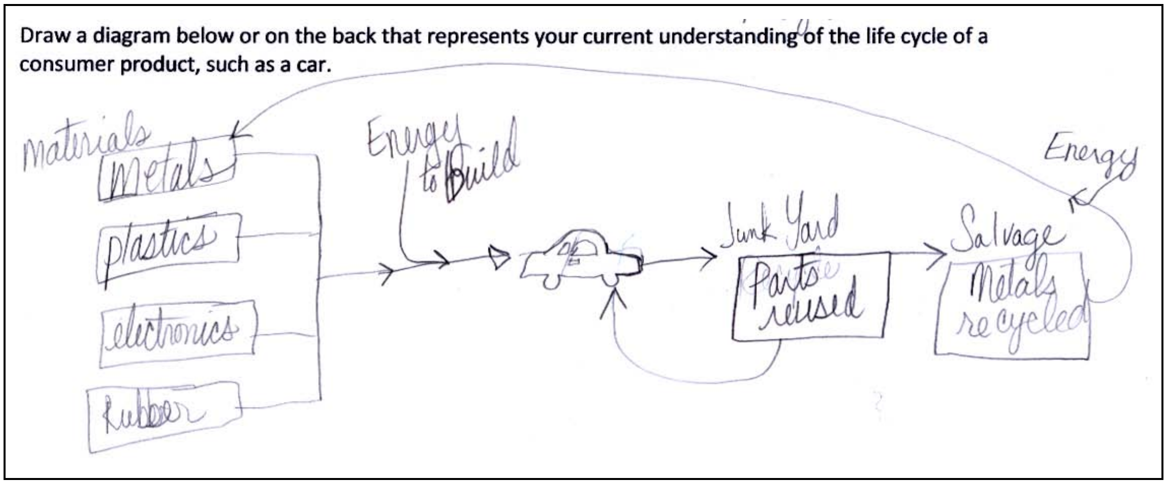

Figure 2: Life Cycle Diagram from Pre-Unit Assessment

Figures 3 and 4 represent two diagrams, made before and after the unit, that show a greater awareness after the unit of stages of the life cycle of a product that are commonly excluded by the average student or consumer: raw material acquisition, manufacturing/production, and transportation. These stages were not only diagrammed and discussed in the LCA lesson but were used to analyze biofuel production during the walkthrough activity and were represented in some way on the cellulosic ethanol spreadsheet.

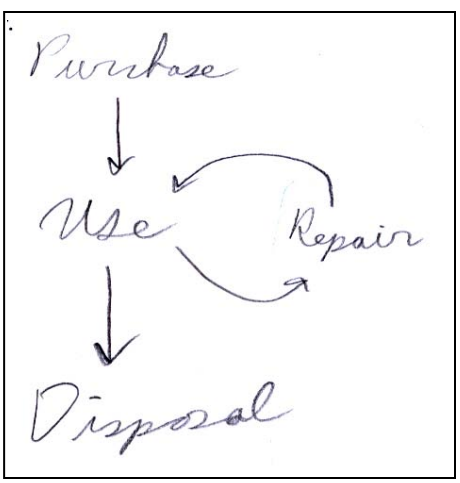

Figure3: Life Cycle Diagram from Pre-Unit Assessment

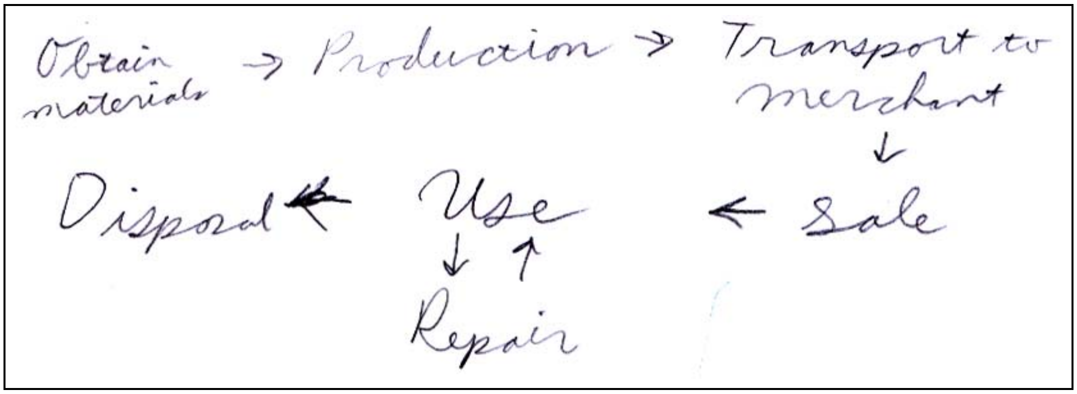

Figure 4: Life Cycle Diagram from Post-Unit Assessment

4.3 – Observations of Student Behavior

One of the evaluation measures of action research is observation of student behavior. While implementing the lessons I made notes about student questions and comments as well as my own ideas for modifications based on observing student behavior, particularly during individual and group activities. At the end of each 3-hour session I recorded my observations in a table, such as the one shown in Figure 5, with additional room for identifying implications of the observations.

The observations were very helpful in improving procedural aspects of the lessons. When students were working on the grocery bag problem set in lesson 1, for example, I observed several students comparing their answers to one step in the problem and getting different results. This particular step in the problem was the one that proved to be the most problematic for students, and will probably need to be broken down for high school students doing the same problem set. I also heard several sets of students asking one another about one part of the directions, implying that some clarification was needed to avoid confusion.

Lesson 2: Biofuels	
Observations	Implications and Questions
concept cartoon - good discussion - agreement on correct answer	would high school students agree so easily?
LC ethanol cycle very easy for most. Some debate/confusion with corn kernel image and bales (2 different feedstocks)	use only images for corn grain (no stover)
walkthrough activity with process tool	
confusion @ fermentation stage (broken into 2 stages)	clarify for fermentation group that they do not need to consider plant operations
Q: when is ethanol mixed w/ gasoline?	clarify in process (add to PowerPoint)
Q: fertilizers →	→ mini-lecture?
students did not use process tool worksheet to map entire process	reinforce correct inputs + outputs at each stage for process tool

Figure 5: Observation Table for Lesson 2

4.4 – Lesson Implementation Survey

A curriculum survey was administered upon completion of the sample unit. The open-ended written responses were analyzed with an emphasis on identifying the success of and suggestions for improving the various instructional strategies used and activities completed. The feedback from the group was particularly helpful as 75% of these adult students are also practicing secondary teachers. The remaining 25% of students are undergraduate students pursuing teacher certification, who do not yet have classroom teaching experience. The practicing teachers average 6.5 years of teaching experience in a wide range of STEM subjects, from environmental science and biology to statistics to Project Lead The Way pre-engineering courses.

The students in the focus group were asked in the survey about various aspects of the unit and lesson design, including content, activities, and instructional strategies. One question asked participants to identify the most challenging or difficult concept in the unit, as well as suggestions for strengthening student understanding of this concept. Table 3 below shows some typical responses:

What do you think is the most challenging or difficult concept addressed in this unit of instruction?	What suggestions do you have for strengthening student understanding of this concept?
Mass and energy transformations	Remediate core biology and chemistry
Chemistry of biofuels	Focus on chemical processes and intermediate molecules (complex carbs to ethanol)
Fermentation – not covered in biology or chemistry TEKS	Do a quick fermentation lab
Students may lack experience in agriculture; farming practices	Watch a farming video as an introduction
Getting students to use their new knowledge	Have a policy debate or make a pamphlet or poster

Table 3: Survey Responses – Challenging Content

The comments mentioned several aspects of the unit, with a few respondents mentioning the complexity of the LCI data on the problem set and spreadsheets; however, most respondents identified the matter and energy tracing, particularly the chemical transformations that occur, as the most challenging content of the unit. These transformations and their interdependence form the core science content of the unit and so must be carefully scaffolded to avoid overwhelming students. Photosynthesis and combustion were easier for students to recall and apply, but fermentation was not a familiar topic for most students.

Students in the focus group were also asked to reflect on the primary instructional activities of the unit. Most responses were positive, and many suggestions were given for improvements. Typical responses are shown in Table 4. The responses reveal that the focus group, given the teaching experience of the members, was able to respond both as students who completed the lessons and teachers with insight into their own practice and recommendations for implementation. In response to the spreadsheet quantitative model that allows students to compare impacts for different types of biomass feedstock, one participant wrote, “Loved it. At first, I was worried that since the spreadsheet was pre-made, it would be easy to ‘plug and chug’ without understanding what you’re doing. But the questions in the worksheet force you to go over the spreadsheet and comprehend what it’s doing.” The teacher responses were very valuable in evaluating the lessons for both content and structure, predicting challenges for implementing in a high school classroom, and identifying important modifications.

Paper vs. Plastic Problem Set
“great way to see the impact of recycling on the impact of the 2 choices”
“many factors not addressed that are a component of real-life ‘paper or plastic’ decision”
“forced me to put numbers to things I usually don’t”
“I enjoyed it but I know most of my students would need a lot of guidance; I would break it down in steps.”
“I thought this was very powerful once the data was put in a graph.”
Life Cycle of Biofuels Walkthrough with Process Tool
“some stages will requires a lot of scaffolding, especially fermentation”
“very well put together, just not very fun”
“a group discussion of each display produced would be helpful to create a class set of charts”
“good…more setup needed to understand how the various components intersect”
Cellulosic Ethanol Quantitative Model (Spreadsheet):
“The spreadsheet is an excellent tool for manipulating the data; separate tabs would be better in my opinion.”
“A little better formatting can allow for all types [of biomass] to be compared side-by-side.”
“The ease of use was great. Students will be likely to try additional analysis with this tool.”
“Needs a method of pacing; maybe create groups with class leaders in each or work through it as a class (timed).”
Alternative Fuel Debate:
“could probably do the same with a ‘coffee talk’”
“Potentially where most learning could occur. I think it should be on policy and not on the science. Use the science and data to inform policy decisions.”
“think it should involve politics”

Table 4: Survey Responses – Activity Reflection

Chapter 5: CONCLUSIONS

The purpose of my action research project was to seek out and examine effective and efficient methods for teaching sustainability to high school engineering students in a way that would develop process analysis skills and science concepts. Upon completion of my project I feel confident that I will be able to continue to modify the unit of instruction to deliver engaging and appropriate lessons that not only introduce relevant concepts in engineering design to students but also deepen their understanding of core science concepts, like energy, that are at the heart of every science discipline.

One of the most challenging aspects of writing and teaching new curriculum is timing. Having the opportunity to preview the lessons with a group of experienced students is a tremendous benefit. We were able to work through several lessons, allowing me the opportunity to see what questions arose during discussions that needed clarification or expansion, which concepts were more difficult for students to grasp, and what issues students had with the presentation, instructions, or procedures of various activities. An additional benefit from working with a focus group that included a majority of experienced secondary STEM teachers was being able to step out of "teacher" mode and talk to them as a colleague about their questions, concerns, or suggestions for the instruction as it was occurring.

The long-term result of the action research will be a more robust curricular unit that has been tested on students and refined for greater instructional impact. For this reason the unit as a whole should be useful to others teaching an engineering science or environmental science course for juniors or seniors in high school. Some aspects, with modifications, could also be applied to an entry-level course for undergraduates. The biggest challenge, perhaps, for applying the revised unit is that it was written to fit into a particular part of a year-long curriculum for engineering science and, therefore, assumes student prior knowledge of topics related to energy systems and the engineering design process.

I was not surprised to read on the surveys that most students responded very favorably to the instructional strategies that incorporated graphics. The concept cartoon to elicit student misconceptions about photosynthesis, the editorial cartoon to spur discussion about ethanol made from corn, and the end-of-unit assessment that asks students to compare two contradictory images related to biofuels were highly rated by the focus group for engagement and effectiveness. I received valuable feedback on administering two of the main activities—the biofuel life cycle "walkthrough" and the cellulosic ethanol spreadsheet model. I have incorporated many of the procedural suggestions, such as adding tabs for each type of biomass to the spreadsheet to facilitate student comparisons between types of biomass products and rewriting instructions for greater clarity.

With regard to content, there is still room for improvement with respect to the biochemistry involved in fuel production. I did feel, as several participants mentioned, that the biochemical processes involved in the creation and use of fuels were the most challenging for students and that this would be even more apparent in a high school classroom. I plan to consult with my school's biology and chemistry teachers to determine to what extent processes like fermentation are covered in their courses as a starting point for addressing these concepts.

One important limitation to the action research was using an adult focus group when the target audience is high school students. Based on my prior work with high school students in life cycle assessment topics, the adult students that participated in the focus group began with a deeper understanding of product sustainability than their teenage counterparts. Teenagers, in my experience, tend to be much more black-and-white in their answers to questions such as "Which is better for the environment: paper or plastic grocery bags?" and tend to give a single reason to justify their response. Adults are more likely to give several diverse reasons why a particular product is better for the environment, and adults are more likely to include energy use as a reason. The adults are also able to diagram the life cycle of a product more completely at the outset of the unit.

Another limitation to the study was not being able to exactly simulate the time constraints of the secondary classroom. During my time with the focus group I was unable to complete all five lessons in the unit. The final lesson, which includes a debate on a policy issue related to biofuels, is meant to deepen student understanding by providing an opportunity to apply both concepts and data learned to larger social issues related to transportation fuels. As one student remarked in the survey, this is "potentially were most learning could occur" and so could be instrumental in helping students take their knowledge to an application level.

In retrospect, I feel that the pre- and post-unit assessment needs revision before being used again with high school students. While I received valuable information from most of the questions, one question that asked about which type of beverage container was best for the environment was too similar to the paper vs. plastic bag question to reveal new insights into student thinking. Instead I believe a question should be added related to fermentation. I am currently unclear about what exposure students have to this concept in earlier science courses; therefore, establishing a base of student knowledge before the unit would be beneficial.

The unit has many possibilities for expansion for use in an engineering science or environmental science course. Once Life Cycle Assessment is known to students it could be used as part of later design challenges to add a sustainability component. A streamlined LCA matrix (Rosselot & Allen, 2000) could be taught and employed as part of the design or re-design process. A fermentation lab would be a good addition for deepening science understanding, and a variety of ethanol-related lab activities are available that could be modified. An expansion of the unit could include the use of LCA software to help students conduct an original LCA. Software is particularly helpful for conducting the detailed inventory that is the most complicated part of the LCA process. Last year students in my class completed a design challenge for an emergency shelter. A component to assess the sustainability of the shelter's materials could be included using software such BEES (Building for Environmental and Economic Sustainability), available online (NIST, 2010).

Action research for education, like teaching itself, is a cyclical process. Curriculum is undergoing constant review and refinement. Even when a lesson becomes "optimized" for time and student engagement, variations in class demographics, yearly schedules, new technologies, and many more factors require that educators continue to modify even very well-established lessons and units. The next step for this unit of instruction will be to present it to a group of students in a high school engineering science course in the 2011-12 school year, evaluate its effectiveness, and make modifications—both during the instruction based on formative assessments and after the instruction based on summative assessments of student work products, including written reflections. I believe this unit has the potential to be one that students remember, and use, in their adult lives as they are faced with complex decisions related to sustainable development.

Appendix A

UNIT PLAN: LIFE CYCLE ASSESSMENT OF BIOFUELS

Based on template in *Understanding by Design* (Wiggins, 2005)

<table>
<tr><th colspan="2">Stage 1 – Desired Results</th></tr>
<tr><td colspan="2">Established Goals:
The student is expected to…
(2)(A) apply scientific processes and concepts outlined in the Texas Essential Knowledge and Skills (TEKS) for Biology, Chemistry, or Physics relevant to engineering design problems;
(2)(B) apply concepts, procedures, and functions outlined in the TEKS for Algebra I, Geometry, or Algebra II relevant to engineering design problems;
(2)(C) select appropriate mathematical models to develop solutions to engineering design problems;
(2)(D) judge the reasonableness of mathematical models and solutions;
(2)(E) investigate and apply relevant chemical, mechanical, biological, electrical, and physical properties of materials to engineering design problems;
(2)(J) use appropriate measurement systems, including customary and International System (SI) units</td></tr>
<tr><td colspan="2">Power Standard: understand and employ a process through which the sustainability of products (or processes) can be quantitatively evaluated</td></tr>
<tr><td>Understandings:
Students will understand that…
Evaluating the sustainability of a product or process requires knowledge of all aspects of that product's life cycle
Life cycle assessment (LCA) is a structured process used to quantitatively evaluate the impacts associated with a product
Biofuels produced from renewable biological resources provide alternatives to conventional gasoline as transportation fuels
Ethanol is an alternative transportation fuel that can be made from a variety of feedstocks, including corn</td><td>Essential Questions:
What makes a product or process sustainable?
How can we evaluate the sustainability of a product?
Should we rely on alternative fuels for our future transportation needs?
How can we apply our knowledge of biofuels to government policy decisions related to fuel sources?</td></tr>
<tr><td>Students will know…
Key terms—life cycle assessment, system boundary, functional unit, biofuel, ethanol, cellulosic ethanol, carbon sequestration
Stages of the life cycle of a product
Defining elements of a life cycle assessment
How biofuels are created
The carbon cycle</td><td>Students will be able to…
Trace carbon and energy through a transportation fuel production system
Describe the steps in fuel processing in which carbon dioxide is sequestered and released
Evaluate the sustainability of gasoline, corn ethanol, and cellulosic ethanol with respect to emissions and energy use</td></tr>
</table>

Stage 2 – Assessment Evidence	
Performance Tasks: • Problem set – students use LCI data to quantitatively compare energy and emissions for two types of grocery bags • Carbon cycle activity – students trace carbon through a transportation fuel production system using a process tool • Energy cycle activity – students trace energy through a transportation fuel production system using a process tool • Spreadsheet – students compare energy requirements to create fuel from different energy crops using a spreadsheet model • In-class debate – students debate the pros and cons of alternative fuel policy	**Other Evidence:** • Pre-unit assessment – understanding student prior knowledge and misconceptions about sustainable products, biofuels, and LCA • Self-assessment – writing in engineering notebook concerning unit concepts and skills learned and used as well as group work • Reflection – writing in engineering notebook concerning the model(s) used in the unit and their reliability and limitations • Post-unit assessment – understanding student knowledge and opinions about sustainable products and biofuels at the end of the unit

Stage 3 – Learning Plan

Learning Activities:

1 Administer the pre-unit assessment to gauge student understanding, attitudes, and misconceptions about sustainable products and biofuels. **W**
2 Use an entry question (Which is better: paper or plastic bags?) to engage students in a real-world discussion of products with differing "green" reputations. **H**
3 Introduce the essential questions and discuss the culminating unit performance tasks. **W**
4 Lead a discussion about Life Cycle Assessment that introduces key concepts and terminology while encouraging student discussion about sustainability choices. **E**
5 Lead the carbon and energy tracing activities that involve whole class cooperative work. **E**
6 Present information on biofuels production. **E**
7 Students use a spreadsheet model to compare the energy requirements to create fuel from different energy crops. **E**
8 Lead an in-class debate concerning the pros and cons of alternative fuel policies. Present case studies to apply to the debate. **O**
9 Student complete self-evaluations regarding individual learning outcomes. **E-2, R**
10 Conclude the unit with a student reflection regarding the reliability and limitations of various models used in the unit. **E-2, R**

What learning experiences and instruction will enable students to achieve the desired results? How will the design…

W = help the students know **W**here the unit is going and **W**hat is expected? Help the teacher know **W**here the students are coming from (prior knowledge, interests)?
H = **H**ook all students and **H**old their interest?
E = **E**quip students, help them **E**xperience the key ideas and **E**xplore the issues?
R = provide opportunities to **R**ethink and **R**evise their understandings and work?
E = allow students to **E**valuate their work and its implications?
T = be **T**ailored to the different needs, interests, and abilities of learners?
O = be **O**rganized to maximize initial and sustained engagement as well as effective learning?

Appendix B

Lesson 1: Introduction to Life Cycle Assessment

Unit	Sustainable Design
Arc	Life Cycle Assessment of Biofuels
Lesson	**Introduction to Life Cycle Assessment**
Prior Knowledge	Life cycles of living organisms, diagramming systems (functional models)
Vocabulary	Life cycle assessment (LCA), life cycle inventory (LCI), functional unit, system boundary, sustainability
Essential Question(s)	*What impact does your lifestyle have on the environment?* *What makes a product or process sustainable?*
Understandings	The student will understand that… • evaluating the sustainability of a product or process requires knowledge of all aspect of that product's life cycle • life cycle assessment (LCA) is a structured process used to quantitatively evaluate the impacts associated with a product
Objectives	The student will be able to… • Describe the stages of the life cycle of a consumer product • Define elements of a life cycle assessment • Use LCI data to compare two products with respect to environmental impacts • Identify limits and challenges to the LCA process/model
Related TEKS	(2)(B) apply concepts, procedures, and functions outlined in the TEKS for Algebra I, Geometry, or Algebra II relevant to engineering design problems; (2)(C) select appropriate mathematical models to develop solutions to engineering design problems; (2)(D) judge the reasonableness of mathematical models and solutions; (2)(E) investigate and apply relevant chemical, mechanical, biological, electrical, and physical properties of materials to engineering design problems
Resources	Allen: online Chapter 13 as background reading and source for problem set
Materials Needed	newsprint or tablet paper, markers, class set of calculators 3 plastic grocery bags, 2 paper grocery bags, groceries to bag for example
Software Needed	PowerPoint with *Life_Cycles.pptx* file, student access to Excel and *LCA_grocery_bags.xlsx* file saved on shared drive
Preparation	Acquire and prepare materials, save Excel file to shared drive Copy *LCA Problems* sheets (1 per student) Copy homework article and entry tickets
Engage (10 min) *grab the students' attention, activate prior knowledge, frame the inquiry*	**OPINION CONTINUUM** *Use the PowerPoint presentation for this lesson to guide all work.* Begin the lesson with an **entry question** to engage students in a discussion of real-world products with different "green" reputations: *Which is better for the environment: paper or plastic bags?* Have students form an opinion continuum with paper on one end, plastic on the other. Students should first share with others around them about their opinions and the reasonings behind them. Then ask each group (paper, plastic, neither/both) to share its ideas. Do not try to "answer" the question, but point out interesting elements of

	student reasoning (for example, both sides might use "easy to recycle" as a rationale for why paper or plastic bags are better). Allow students to reposition themselves on the continuum, if desired.
Explore (15 min) *grounding experience with materials and phenomenon, create base of common experience*	**ANNOTATED SKETCHES** Ask students to silently consider the "life story" of an athletic shoe. They should consider the questions posed on the PowerPoint slide to spur their thinking. Organize students into small groups. Ask them to spend a few minutes sharing ideas and answering the questions posed. Once students have had time to discuss, point out to them that their life stories have some beginning point, some middle stages, and an end. Ask, *How can you represent this life story as a diagram?* Each group should create a diagram on poster-sized chart paper using markers. Once the stages have been recorded, students should add arrows to represent "flow" from one stage to another. Next to each stage students should record as many details as possible, including kinds of *processing* that might occur at that stage, the *inputs* (anything that enters the system), the *outputs* (anything that exits the system). *Note: adding processing, inputs, and outputs is very challenging for most students; remind them of work done in the reverse engineering unit on functional modeling that also included inputs and outputs.* Share diagrams with the whole class by posting the papers side-by-side. Look for similarities and differences between the diagrams. Ask students to identify further questions: *What do they Need To Know to make a better diagram?* Record these questions for later discussion, but do NOT answer them at this time. Introduce one of the essential questions of the unit that we will work towards answering in this lesson: *What makes a product or process sustainable?*
Explain (20 min) *clarify and articulate underlying concepts*	Continue to use the **PowerPoint presentation** with built-in questioning to lead a discussion about **Life Cycle Assessment** that introduces key concepts and terminology while encouraging student discussion about sustainability choices. Students should take notes in their engineering notebooks during the presentation and discussion. Topics introduced and discussed include: • Definition of life cycle and life cycle assessment • Reasons for conducting and studying LCAs • 4 steps for conducting LCAs • LCA terminology: system boundary, functional unit • Evaluating the limitations and uncertainties of the LCA model
Elaborate (35 min) *expand on concepts, make connections, real-world experience, further inquiry*	**LIFE CYCLE ASSESSMENT PROBLEM SET** Distribute the *LCA Problems* sheet to each student. Introduce the activity using the PowerPoint slide. Discuss the system boundaries and the importance of establishing the functional unit. Use the sample groceries and bags to demonstrate (or have students demonstrate) equivalency between paper and plastic bags. Review the question and the provided diagram and ensure that all students understand and record the functional unit/equivalency to be used. Give students time to read part a), discuss it with their groups, and then ask questions as needed. As students work, circulate between groups to answer questions, check

	calculations, and redirect work as needed. Help students set up their calculations and encourage groups to compare answers. As student finish a), they can move to computers to begin part b), where they will need to use Excel. There is a template file already created that allows them to enter their data without spending time formatting the document. Once they have entered their own data, they will need to insert a "Line with Markers" graph from the selected data and format it appropriately. It might be necessary to have a just-in-time teaching session on inserting and formatting graphs in Excel.
Evaluate (10 min) *ongoing assessment appropriate for content*	The last two questions on the LCA Problems sheet ask the students to evaluate. First they evaluate their results and determine whether or not these results allow for a comprehensive comparison of the two types of grocery sacks. The last question asks students to reflect on their own understandings of the environmental impacts of grocery bags and compare any new understandings to their prior conceptions.
Extend (homework)	Ask students to read the one-page summary of the Stonyfield Farms yogurt packaging LCA. Give each student a half-page entry ticket to be turned in at the beginning of the next class.
Differentiation Plans:	*How will you modify the lesson to meet the needs of students working above or below grade level? How will you make these students connect with the lesson's Big Ideas in a meaningful, appropriate way?*
Students above grade level *How will you modify the lesson's objectives to meet the needs of students working above grade level?*	During group work use open-ended guiding questions to spur deeper student thinking about life cycle concepts. Challenge students to add more depth to their life cycle diagrams by developing Need To Know questions for each stage. Ask students with Excel skills to assist others by providing a demonstration.
Students below grade level *How will you modify the lesson's objectives to meet the needs of students working below grade level?*	Partner students carefully to ensure that all students are comfortable making contributions to the lesson's work and are able to share ideas with the whole group. During group work use guiding questions to spur student thinking about life cycle concepts. Built in to the lesson – small group work to allow students to share ideas with peers before being asked to share with whole class Observe group work during the calculation and spreadsheet activities to ensure that all students are contributing, and not just writing down answers provided by others or passively observing.

LESSON 2: INTRODUCTION TO BIOFUELS

Unit	Sustainable Design
Arc	Life Cycle Assessment of Biofuels
Lesson	**Introduction to Biofuels**
Prior Knowledge	Carbon cycle, energy transfer
Vocabulary	Biofuel, ethanol, photosynthesis, fermentation, combustion, biomass, glucose
Essential Question(s)	*Can alternative fuels provide for our transportation needs now and in the future?*
Understandings	The student will understand that… • Over long spans of time, matter and energy are transformed among living things, and between them and the physical environment. In these grand-scale cycles, the total amount of matter and energy remains constant, even though their form and location undergo continual change *(adult science literacy expectations regarding photosynthesis)* • Biofuels produced from renewable biological resources provide alternatives to conventional gasoline as transportation fuels. • Ethanol is an alternative transportation fuels that can be made from a variety of feedstocks, including corn.
Objectives	The student will be able to… • Trace carbon and energy through a transportation fuel production system • Describe how biofuels are created • Describe the steps in fuel processing in which carbon dioxide is sequestered and released
Related TEKS	(2)(A) apply scientific processes and concepts outlined in the TEKS for Biology, Chemistry, or Physics relevant to engineering design problems; (2)(E) investigate and apply relevant chemical, mechanical, biological, electrical, and physical properties of materials to engineering design problems
Resources	
Materials Needed	Clear tape, glue sticks, printed color images (set of 10) for each student group of 3 or 4, poster-sized chart paper sheets (2 per group), printed color images for life cycle stages
Software Needed	PowerPoint with *Biofuels.pptx* file
Preparation	Acquire and prepare materials Print (color) images for explore activity, cut Print (color) signs for carbon/energy tracing activity, cut, hang Copy homework reading
Engage (10 min) *grab the students' attention, activate prior knowledge, frame the inquiry*	**CONCEPT CARTOON** Using the PowerPoint presentation for this lesson, make the connection between the previous lesson's focus on LCA and the focus of the rest of the unit: biofuels. Lead a discussion on why we want/need to develop alternative fuels and what kinds of alternative fuels are being developed. Introduce the EISA legislation. Then focus in on biofuels and ask students what we Need To Know to compare biofuels to conventional fuels. Show the class the concept cartoon for the question "Where Does a Plant's Mass Come From?" Ask students to read and think silently for a minute to process the question and choose an answer of their own. Organize students into small groups to discuss and give them a couple of minutes to determine their answer to the cartoon, allowing them to

	confront their individual conceptions as well as those of their peers. Ask each group to share their chosen answer. As a whole group, discuss questions students have about photosynthesis and what they Need To Know. Do NOT give the answer—it will become apparent through the course of the lesson and will be discussed again at the end. Briefly explain how this concept applies to today's lesson—how biofuels are created.
Explore (10 min) *grounding experience with materials and phenomenon, create base of common experience*	**LIFE CYCLE DIAGRAM** Organize students into small groups and give each group a poster-sized paper, a glue stick, and a set of printed color images that depict the stages of creation for a biofuel (particularly ethanol is depicted). Ask students to spend a few minutes discussing the images and what they represent and then arranging them on the large poster paper into a diagram that represents the life cycle of a biofuel. Share diagrams with the whole class by posting the papers side-by-side. Look for similarities and differences between the diagrams. Ask students to identify further questions: *What do they Need To Know to make a better diagram?* Record these questions for later discussion, but do NOT answer them at this time.
Explain (10 min) *clarify and articulate underlying concepts*	**CARBON CYCLE** Continue to use the PowerPoint presentation with built-in questioning to lead a discussion about the carbon cycle that reviews/introduces key concepts and terminology while encouraging student discussion.
Elaborate (45 min) *expand on concepts, make connections, real-world experience, further inquiry*	**LIFE CYCLE WALKTHROUGH** Lead the carbon and energy tracing activity that involves whole class cooperative work. The detailed instructions are on the second page of this document. During the activity, at each stage of the ethanol life cycle once students have shared their ideas about the matter and energy inputs and outputs for that stage, use the PowerPoint to discuss the inputs and outputs for both carbon and energy. Students can then check their work, discuss differences, and ask questions.
Evaluate (5 min)	Revisit the cartoon and discuss how students would answer the question about biomass production after completing the carbon tracing activity.
Evaluate (10 min) *ongoing assessment appropriate for content*	To help students make connections about the lesson concepts and gauge student understandings, use the **3-2-1 Summarizer** technique, a tool for summarizing and connecting ideas from a lesson or unit. Students record: 3 – facts about biofuels 2 – interpretations, judgments, or conclusions 1 – connection, application, or speculation This individual response can be completed in notebooks or on a sheet to be handed in to the teacher for review before the following lesson.
Extend (homework)	Pass out the reading from The NEED Project consisting of two one-page summaries of gasoline and ethanol. Inform students that the following lesson's opening activity will require information from the reading.
Differentiation Plans:	*How will you modify the lesson to meet the needs of students working above or below grade level or who are LEP? How will you make these students connect with the lesson's Big Ideas in a meaningful, appropriate way?*
Students above grade level	During group work use open-ended guiding questions to spur deeper student thinking about carbon and energy transfers during biofuel

	production. Assign students to the more difficult stages (like Farming Practices) during the biofuel life cycle walkthrough activity, and challenge them to describe as many possible inputs and outputs as they can.
Students below grade level	Partner students carefully to ensure that all students are comfortable making contributions to the lesson's work and are able to share ideas with the whole group. During group work use guiding questions to spur student thinking about carbon and energy transfers during biofuel production. Built in to the lesson – small group work to allow students to share ideas with peers before being asked to share with whole class.
LEP students	Biofuel life cycle "explore" activity relies on images rather than words to spur student thinking and incorporate prior knowledge. Use images to help ground new terminology with visual aids.

LESSON 3: CELLULOSIC ETHANOL – ENERGY MODEL

Unit	Sustainable Design
Arc	Life Cycle Assessment of Biofuels
Lesson	**Cellulosic Ethanol: Energy Model**
Prior Knowledge	Carbon cycle, energy transfer, life cycle assessment (LCA)
Vocabulary	life cycle assessment (LCA), biofuel, ethanol, biomass, feedstock, carbon neutral, cellulose, lignin, hemicellulose
Essential Question(s)	*Can alternative fuels provide for our transportation needs now and in the future?*
Understandings	The student will understand that… • Biofuels produced from renewable biological resources provide alternatives to conventional gasoline as transportation fuels • Ethanol is an alternative transportation fuel that can be made from a variety of feedstocks, including corn • A life cycle model can be used to evaluate the net energy produced for biofuels
Objectives	The student will be able to: • Define cellulose and describe how cellulose is created in plants • Describe the industrial process used to break down cellulose • Compare energy requirements to create fuel from different energy crops • Use a spreadsheet to evaluate a simple life cycle model for a process • Explain the concepts of net energy for a process • Discuss the pros and cons of creating biofuels from different crops under different circumstances
Related TEKS	(2)(A) apply scientific processes and concepts outlined in the biology, chemistry, or physics TEKS relevant to engineering design problems (2)(C) select appropriate mathematical models to develop solutions to engineering design problems;
Resources	Document camera, projector with speakers, ability to play video, video file from website; computers with Excel
Materials Needed	Printed copies of student instructions or file saved on shared drive Printed copies of student worksheet for quantitative model Printed copies of background reading
Software Needed	PowerPoint with *Cellulosic_Ethanol.pptx* file Microsoft Excel with LCA document saved on shared drive
Preparation	Print and copy student handouts and worksheets. Save LCA Excel document to the shared drive for student access. Copy background reading, "Why is it so difficult to make cellulosic ethanol?" Access necessary videos with sound before class begins.
Engage (5 min)	**EDITORIAL CARTOON** Use the PowerPoint presentation on Cellulosic Ethanol to show the class an editorial cartoon about ethanol. Ask the class to quietly consider the message of the cartoon for a minute and then briefly share with a partner how they interpret the cartoon. *What is the illustrator trying to convey about ethanol made from corn?* *What are the facts to support this view?* Show the following slide from the USDA website, that give some facts about corn production over the past 30 years. Ask students to study the graph. *What can we say about corn production over time?*

<table>
<tr><td>Explain (20 min)
clarify and articulate underlying concepts</td><td>CELLULOSIC ETHANOL
Provide background information on cellulosic ethanol and how it is produced. Students will need a basic understanding of the differences between corn ethanol and cellulosic ethanol.
Before showing the video, introduce it and ask students to watch for descriptions of the process of making cellulosic ethanol as well as claims made in support of cellulosic ethanol as a fuel.
Show the video, available from the website: http://www.nrel.gov/learning/re_biofuels.html This is a 5-minute summary of the difference between corn and cellulosic ethanol and the process currently used to make cellulosic ethanol.
At the conclusion of the video, ask for student questions or comments. Clarify any questions, or defer to the more in-depth work later in the lesson, as necessary.
Use the PowerPoint presentation on cellulose to introduce the concepts below:
Types of plant materials
Composition of cellulose
How cellulose must be broken down into simple sugars
Steps in processing cellulose into ethanol</td></tr>
<tr><td>Explore (20 min)
grounding experience with materials and phenomenon, create base of common experience</td><td>STUDENT KNOWLEDGE SHARING
There is a five-page document that describes some of the assumptions made and calculations used to create the spreadsheet model. This can be assigned as homework reading and a follow-up discussion can be led by the teacher to ensure comprehension.
<u>EACH ONE TEACH ONE</u>: Alternatively, the sixteen big ideas upon which the spreadsheet model is created can be assigned to individuals, or groups of 2 if necessary. Each student is given a paragraph or two to read, has time to read it, and time to ask questions about the information or values given.
Each student presents his/her topic to the class in 1 minute or less. The teacher will need to fill in missing information by asking leading questions so that all students understand the basis upon which the spreadsheet calculations are determined. (farm size, three feedstocks, crop yield, energy content, 5 energy uses during plant growth, 5 energy uses during processing)
A graphic organizer can be given for students to complete as other students are presenting key ideas.</td></tr>
<tr><td>Elaborate (40 min)
expand on concepts, make connections, real-world experience, further inquiry</td><td>QUANTITATIVE LCA MODEL FOR CELLULOSIC ETHANOL FEEDSTOCKS
Use the PowerPoint slide to read the quantitative LCA scenario to the class to introduce the context for the quantitative modeling activity.
Introduce the spreadsheet model, the instructions, and the worksheet to record results. Show some of the equations pre-entered in the spreadsheet so that they understand how the spreadsheet works.
Note: if you would like students to determine how to make the calculations, unprotect the sheet and delete the equations from the blank spreadsheet before giving the file to students. With pre-entered equations, students can complete the spreadsheet very quickly.
Once students have entered data and received results they should complete the worksheet for the energy model. If working in teams, they should share data and compare results before answering the questions.</td></tr>
</table>

	Have students run alternative scenarios for energy. Provide them with scenarios or encourage them to create their own questions, such as: • *What if we didn't have ideal growing conditions?* • *What if I wanted to use fewer chemicals to reduce pollution or cut costs?* Evaluate which questions can and cannot be answered with this particular model. Return the groups to their spreadsheets using the alternative scenarios. They should prepare a second summary of their new scenario and compare it to their initial summary. They should calculate the percentage change so that individuals or teams can easily compare results. Discuss the new results as a class. Show the corn grain ethanol data (from the answer key document) as a basis to compare the current technology. Discuss the strengths and limitations of the model. Consider concerns other than energy, such as biodiversity, water use, greenhouse gas emissions, or a farmer's profitability.
Evaluate (5 min) *ongoing assessment appropriate for content*	**QUICK WRITE** Students should reflect in their engineering notebooks on a prompt, such as: *Does producing liquid fuels from biomass provide a net energy gain?* [yes] *Where did that energy come from?* [the sun] *Where do you think it would be most valuable to put research efforts to improve the efficiency of the system?*
Extend (Homework)	Pass out the background reading, "Why is it so difficult to make cellulosic ethanol?"
Differentiation Plans:	*How will you modify the lesson to meet the needs of students working above or below grade level? How will you make these students connect with the lesson's Big Ideas in a meaningful, appropriate way?*
Students above grade level	When topics are assigned for the Student Knowledge Sharing activity, give advanced students topics for which there is more information to be comprehended and shared back with the whole group, such as energy content or energy use in planting. The spreadsheet model currently includes equations. Some or all of these can be deleted and students asked to determine how a calculation should be made. This can be done individually, in small groups, or with the whole class.
Students below grade level	During the Student Knowledge Sharing activity, check in with students about their assigned topics to ensure understanding and allow them to ask questions before sharing with the whole group.

LESSON 4: CELLULOSIC ETHANOL – EMISSIONS MODEL

Unit	Sustainable Design
Arc	Life Cycle Assessment of Biofuels
Lesson	**Cellulosic Ethanol: Emissions Model**
Prior Knowledge	Carbon cycle, energy transfer, life cycle assessment (LCA)
Vocabulary	life cycle assessment (LCA), biofuel, ethanol, biomass, cellulosic ethanol, feedstock, greenhouse gas (GHG), emissions
Essential Question(s)	*Can alternative fuels provide for our transportation needs now and in the future?*
Understandings	The student will understand that… • Biofuels produced from renewable biological resources provide alternatives to conventional gasoline as transportation fuels • Ethanol is an alternative transportation fuel that can be made from a variety of feedstocks, including corn • A life cycle model can be used to evaluate the net energy produced for biofuels
Objectives	The student will be able to: • Use a spreadsheet to evaluate a simple life cycle model for a process • Explain the concepts of net energy and net GHG emission for a process • Identify opportunities for reducing net GHG emissions through agricultural practices • Describe the assumptions, boundaries, and limitations of a life cycle model • Discuss the pros and cons of creating biofuels from different crops under different circumstances
Related TEKS	(2)(A) apply scientific processes and concepts outlined in the biology, chemistry, or physics TEKS relevant to engineering design problems (2)(C) select appropriate mathematical models to develop solutions to engineering design problems; (2)(D) judge the reasonableness of mathematical models and solutions
Resources	Document camera, projector with speakers, ability to play video, video file from website; computers with Excel
Materials Needed	Printed copies of student instructions or file saved on shared drive Printed copies of student worksheet for quantitative model Printed copies of background reading
Software Needed	PowerPoint with *Greenhouse_Gas.pptx* file Microsoft Excel with LCA file saved on shared drive
Preparation	Print and copy student handouts and worksheets. Save LCA Excel document to the shared drive for student access. Copy background reading on biofuel policy.
Engage (5 min)	Using the PowerPoint presentation, ask the class: *"Imagine it is winter, and you have been having clear, sunny weather. One morning you look out the window and see that it is very cloudy. How do you think the temperature outside will compare to yesterday's?"* Discuss all answers, asking the class to come to a consensus.
Explain (15 min) *clarify and articulate underlying concepts*	Use the PowerPoint presentation on greenhouse gas emissions to introduce the concepts below: • Greenhouse gases • Emissions

	• CO_2 and combustion Show a short video related to greenhouse gases and/or carbon dioxide, such as the one about carbon dioxide found at http://www.teachersdomain.org/resource/phy03.sci.ess.watcyc.co2/ Review the quantitative LCA scenario. Recap the work done on energy inputs for the three types of cellulosic ethanol and focus student attention on using Life Cycle data to examine the impact of different ethanol feedstocks on GHG emissions. Review background information on GHG and LCA, paying particular emphasis to carbon dioxide equivalents, particularly the functional unit used of kilogram carbon dioxide equivalents per liter of cellulosic ethanol ($kgCO_2eq/L$). Establish a gasoline baseline with which to compare cellulosic ethanol, as well as a corn-grain baseline.
Explore (25 min) *grounding experience with materials and phenomenon, create base of common experience*	**QUANTITATIVE LCA MODEL FOR CELLULOSIC ETHANOL FEEDSTOCKS** To ensure student comfort with, and understanding of, dimensional analysis, work through the switchgrass model together as a class and then have students work individually or with a partner for the other feedstocks using the Excel spreadsheet. Once students have entered data and received results they should complete the worksheet for the emissions model. If working in teams, they should share data and compare results before answering the questions.
Elaborate (30 min) *expand on concepts, make connections, real-world experience, further inquiry*	After results have been obtained, bring the class together to discuss the results. Students should be able to discuss the following concepts: • Greenhouse gas carbon dioxide equivalents used in the model • How different feedstocks compare to gasoline and corn grain ethanol • The benefits of using models as predictors of real world situations • The limitations of using models as predictors of real world situations Use a discussion-facilitation technique to ensure all students contribute.
Evaluate (15 min) *ongoing assessment appropriate for content*	**QUICK WRITE** Return to the original scenario. Ask students to write (in their engineering notebooks) a summary report to the farm cooperative members about which feedstock(s) they believe are the best choice. They should support their response with data from the energy and emissions activities. They should also state which assumptions they are using (fertilizer use, etc.) If time allows, the Quick Write summary can be extended to encompass a more formal and comprehensive technical report that includes a summary of findings for both energy and emissions and a final recommendation with supporting data.
Extend (Homework)	Pass out the background reading that summarizes current US biofuel policy. Inform students that they will be debating policies in the next lesson, so reading the background info will be crucial for successful participation.
Differentiation Plans:	*How will you modify the lesson to meet the needs of students working above or below grade level? How will you make these students connect with the lesson's Big Ideas in a meaningful, appropriate way?*
Students above grade level	The spreadsheet model currently includes equations. Some or all of these can be deleted and students asked to determine how a calculation should be made. This can be done individually, in small groups, or with whole class. Students can create graphs comparing the feedstocks or scenarios.

Students below grade level	Provide assistance with understanding formulas in the spreadsheet—how they are entered and what they mean for the data used. Provide assistance with dimensional analysis, as needed.

LESSON 5: BIOFUELS POLICY DEBATE

Unit	Sustainable Design
Arc	Life Cycle Assessment of Biofuels
Lesson	**Debating Biofuel Policy**
Prior Knowledge/Skills	LCA, biofuel production, ethanol, cellulosic ethanol, GHG emissions
Vocabulary	Life cycle assessment (LCA), biofuel, cellulosic ethanol, carbon neutral, government subsidies
Essential Question(s)	*How can we apply our knowledge of biofuels to government policy decisions related to fuel sources?*
Understandings	The student will understand that… • All fuel sources have inherent advantages and disadvantages • Knowledge of the life cycles of fuel sources assists with evaluating existing government policies and making informed policy decisions
Objectives	The student will be able to: • Describe the function and rules of a debate • Research and analyze to prepare to participate in a debate • Participate appropriately in a classroom debate about fuel policies • Discuss the pros and cons of biofuels and related policies
Related TEKS	(4)(E) discuss the history and importance of engineering innovation on the American economy and quality of life; (6)(C) work in teams and share responsibilities, acknowledging, encouraging, and valuing contributions of all team members;
Resources	Access to computers for research
Materials Needed	Index cards for debate preparation Summary sheet of current US biofuel policies
Software Needed	PowerPoint with *Fuel_Debate.pptx* file
Preparation & Set-Up	Copy summary sheet

Engage (10 min)	Show students a video of a formal debate. Ask them to observe the procedures and the roles of the participants. Discuss the role and procedures of a debate with the class. • *What is the purpose of a debate?* • *What are some of the rules of a debate, based on your observations?* • *What is necessary to prepare to participate in a debate?*
Explore (25 min) *grounding experience with materials and phenomenon, create base of common experience*	Assign student groups for the debate. Organize teams accordingly based on class size and number of policies to be discussed. Assign one policy question to two teams, and explain that some the teams will not know whether they are supporting the policy or not until just before the debate begins. Even if they disagree with the policy, they still must support it to the best of their ability in the debate! Students work with their groups to organize their ideas, research data on their policy or fuel facts, and assign roles or tasks as needed. Work with students groups to ensure they are well prepared. They might want to use index cards to organize their key points, or other aids. Several students can be assigned to be the audience. They should prepare an evaluation tool to compare the debate teams. A blank table rubric can be used that they can fill in with their criteria.
Explain (5 min) *clarify and articulate*	Explain the debate procedures to the class. Ensure that everyone understands the role they are to play, and that everyone is expected to

underlying concepts	participate meaningfully. Explain the evaluation tool created by the audience team.
Elaborate (35 min) *expand on concepts, make connections, real-world experience, further inquiry*	**BIOFUEL POLICY DEBATE** Organize the class for the debate. Have teams sitting together, separated from one another, facing the teacher and student audience. Lead a class-wide debate on transportation fuel policies: Pose a question to one team. They have up to one minute answer the question. Encourage them to quietly organize their thoughts/notes before answering. At the end of the first response, move to another student group and give them the same amount of time to respond to the question. They can (and should) make reference to other teams' responses. Continue until all groups have answered the questions. Allow each group to make a summary statement to persuade the audience. The audience then has a few minutes to compare notes and confer before declaring a "winner" based on the evaluation rubric.
Evaluate (15 min) *ongoing assessment appropriate for content*	Administer the post-unit assessment to all students. **QUICK WRITE** Ask students to reflect on the debate process.
Extend (Homework)	Any reflection not completed during the unit can be completed for homework. Any incomplete work in the engineering notebook can be completed for homework.
Differentiation Plans:	*How will you modify the lesson to meet the needs of students working above or below grade level? How will you make these students connect with the lesson's Big Ideas in a meaningful, appropriate way?*
Students above grade level	Ensure that students are well-distributed in student debate teams. Challenge students to incorporate information from the spreadsheet models into their responses.
Students below grade level	Ensure that students are well-distributed in student debate teams. Ensure that all students understand their role in the debate and how they can contribute meaningfully. Help a student prepare for a specific type of question.

Appendix C

My work throughout the UTeach Engineering MASEE program has prepared me well to represent engineering careers and practices to my current and future students. I have been exposed to a variety of engineering disciplines and practices and have experienced first-hand how the engineering design process can be applied in a variety of disciplines. My personal background in architectural design prepared me extensively for work with the design process, but its application in engineering is a bit different. I have always felt well-prepared to discuss architectural careers and practices with students based on my own undergraduate and employment history, and now I feel I can comfortably discuss engineering careers and practices as well.

A challenge for me throughout the program has been to develop engineering habits of mind, given my architectural background. In architectural design, much of the design work is graphic—with solutions being generated, developed, and analyzed through 2D and 3D models of spaces. While there is certainly quantification involved—of client needs, budgets, building materials, etc.—architectural design does not rely on mathematical and scientific models as a prime generator of design solutions. It has been enlightening to work with engineering faculty and my fellow STEM educators on engineering design challenges, and I have been able to incorporate much of what I have learned into both existing and new design challenges for my students at all levels of instruction.

In addition to engineering content, I have grown with respect to instructional theory throughout the MASEE program. The educational theory courses as well as work done with the consultant group Educators for Social Responsibility (ESR) have strengthened my foundation in the theory of constructivism and strategies such as formative assessment, backwards design for teaching units and lessons, and the 5E lesson plan. ESR has worked with schools in the Austin school district on implementing high school redesign, with a focus on improving classroom instruction rather than restructuring the school. Several of their resources have been vital to restructuring my own understanding of highly-effective instruction and served as references for this report.

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