AC 2011-369: TEACHING SUSTAINABILITY ANALYSIS IN ELECTRONICS LECTURE COURSES

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Teaching Sustainability Analysis in Electronics Lecture Courses

Abstract

Based on positive prior experiences teaching sustainability analysis in electronics laboratory courses, this work explores techniques for teaching sustainability analysis in lecture courses. As difficult as it may seem to incorporate sustainability into integrated circuit courses or other engineering courses, it may prove as easy as asking students to consider how the coursework relates to sustainability issues.

The need to educate students "to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" has gained sufficient value to deserve its own ABET Program Outcome, Criterion 3(c). This work presents a strategy to introduce students to the relevant issues before senior design coursework, thereby providing practice and enabling them to achieve such a program outcome more skillfully in senior level classes. Key practical challenges arise when attempting to add learning content to a one-quarter electronics course already bursting at the seams with conceptually challenging learning outcomes:

1. No extra class time exists in which to insert additional in-class activities; and
2. Few instructors desire the increased workload associated with reading dozens of additional student essays on top of normal assignment grading.

To address the in-class time limitation, this work delivers the sustainability issues content online. To minimize excess faculty workload, this work presents a tool designed to assist faculty to use peer review of writing assignments, even in medium to large courses. Assessment data confirm the students assimilate new sustainability analysis skills.

Introduction

ABET Program Outcome, Criterion 3(c) describes the need to educate students "to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability."[1] This work presents a strategy to introduce students to the relevant issues in earlier coursework and to provide practice enabling them to achieve skillfully such a program outcome in senior level design classes. After reviewing multidisciplinary sustainability definitions, this paper explains how students learn how to use a systems approach to analyze sustainability issues.

In contrast to a previously tested similar approach using weekly writing assignments in laboratory courses,[2] this work compares the effectiveness of a single assignment in a lecture course. The proposed method has students write about sustainability issues associated with their engineering topics. Supplying online resources minimizes the in-class time required, and peer review reduces the instructor workload. While this work incorporates sustainability into integrated circuit courses, it should generalize to other engineering courses, by asking students to consider how their coursework relates to sustainability. The assessment data suggest students improve their sustainability analysis skills.

Sustainability Learning Objectives

The context for this work is the 3-unit lecture course, EE 306, titled *Semiconductor Device Electronics* and accompanied by a 1-unit laboratory course, EE 346, titled *Semiconductor Device Electronics Laboratory*, given at California Polytechnic State University (Cal Poly). The courses form the first quarter of a three quarter sequence of electronics courses during the junior year, following a year of introductory circuit analysis courses. EE 306 and EE 346 are required courses for Electrical Engineering and Computer Engineering majors. The general course learning objectives are the abilities to

- Model electronic devices and explain how terminal characteristics depend on underlying scientific principles;
- Use semiconductor material theory sufficiently to explain the operation of PN junction diodes and transistors (FETs and BJTs);
- Select and apply the appropriate circuit models to represent the behavior of diodes and transistors in standard modes of operation;
- Analyze diode and transistor circuits by hand and with the aid of a computer;
- Obtain the small-signal device parameters of FETs and BJTs; and
- Specify components for inverters and single stage amplifiers.

A complete list of learning outcomes appears online.[3] Compared to topics and outcomes described by the Computer Engineering 2004 Joint Task Force on Computer Engineering Curricula, Cal Poly course coverage corresponds approximately to Electronics areas CE-ELE3 through CE-ELE8 as well as a few topics in the VLSI areas.[4] The course also seeks to prepare students for subsequent required courses in digital electronics, analog electronics, mixed-signal electronics, and embedded systems as well as technical electives in analog electronics, power electronics, and VLSI areas. The most recent course syllabus details course mechanics and the course schedules for reading, homework, laboratory experiments, lab reports, quizzes, and the final exam.[5] Primarily the laboratory consists of weekly experiments, which the students document in weekly lab reports.

More generally, the course assists students to achieve ABET outcomes 3a, 3b, 3c, 3e, 3g, and 3k, and clearly emphasizes an ambitious list of technical topics rather than sustainability. Recognizing the situational factors acting to constrain course boundaries and student time, this attempt to teach sustainability in a topic-rich lecture course helps students achieve two sustainability learning objectives:

1. Articulate one or more definitions of sustainability.
2. Explain how electronics experiments relate to sustainability issues.

The following sections expand on the above two objectives.

Sustainability Definitions

While numerous sustainability definitions exist, several nicely convey how sustainability depends on multidisciplinary and systems thinking. A definition from Euston and Gibson describes sustainability as "a condition in which natural systems and social systems survive and thrive together indefinitely."[6] This approach naturally evokes the Venn diagram of Fig. 1 showing that sustainability can exist where the four "E" *Environmental*, *Energy*, *Economic*, and

social and political *Equity* considerations overlap. A lengthier list of "E" constraints could include *Ecology, Education*, and *Ethics*. A sustainable society allows each human being the opportunity to develop in freedom, within a well-balanced society and in harmony with its surroundings.[7] As described by McDonough, "the goal is a delightfully diverse, safe, healthy, and just world, with clean air, soil, water, and power, economically, equitably, ecologically, and elegantly enjoyed."[8] To achieve sustainability, McDonough works to "design systems that love all the children of all species for all time."[8] Such a multidisciplinary backdrop creates a more nuanced view of the original Brundtland Commission definition of sustainable development, which seeks a way to meet the needs of the present without compromising the ability of future generations to meet their own needs.[9]

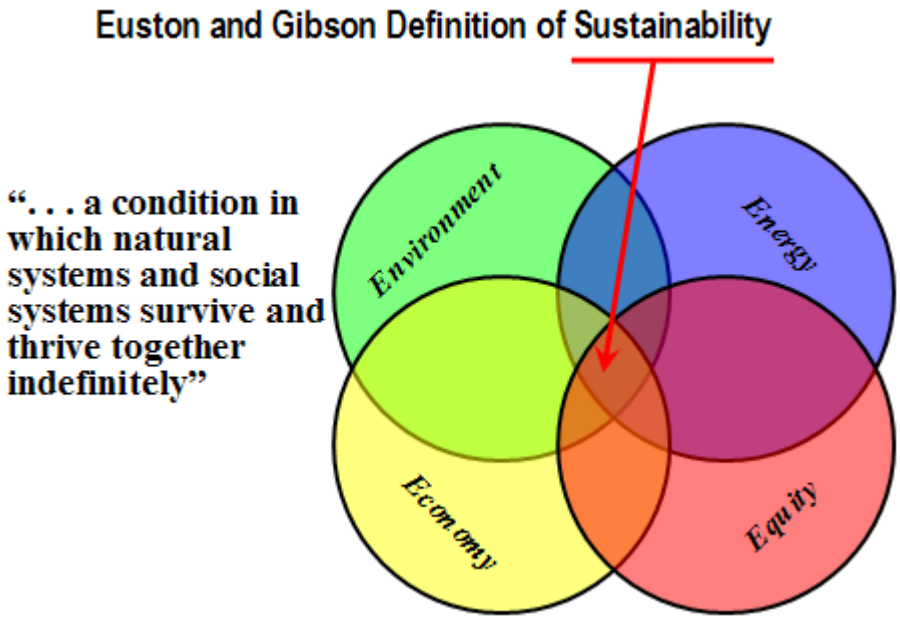

Figure 1. Sustainability Venn diagram motivated by the Euston & Gibson definition of sustainability[6] and James White's four sustainability "E"s.[10]

4E Sustainability Analysis

To explore sustainability issues in electronics experiments, this work employs the proposed 4E Sustainability Analysis technique. By writing sustainability analyses, students learn to explain how engineering experiments, their applications, and their impacts foster or prevent sustainability. Analyses uncover energy and resource issues in engineering topics and relate them to sustainability issues. The analyses involve environmental, social, political, and economic aspects. In select engineering courses, the author had students post their sustainability analysis work on individual or common wikis. See http://sustainability-and-ICs.pbworks.com/.[11] The wiki contains a brief introduction to sustainability, sustainability data, and examples of sustainability analyses written by students in several engineering course sections. Having students address questions about four sustainability "E" areas can help them navigate more surely through sustainability analysis. Figure 2 contains questions designed to lead students to make connections between engineering topics and the highlighted sustainability areas.

Ecology

1. Which natural resources and ecosystem services does the experiment use directly and indirectly?
2. Which natural resources and ecosystem services does the experiment improve or harm?
3. What ecological impacts result? Where? How much?
4. How does the project impact other species?

Energy

1. How much energy does the experiment use?
2. From which sources?
3. Are the energy sources renewable, efficient, or polluting?
4. What impacts result?
5. Are all material and energy inputs and outputs as inherently safe and benign as possible?

Economy

1. What economic impacts result? Consider:
   - Human Capital – What people do.
   - Financial Capital – Monetary instruments.
   - Manufactured or Real Capital – Made by people and their tools.
   - Natural Capital – The Earth's resources and bio-capacity.
2. How much does the experiment cost? Who pays?
3. How much does the experiment earn? Who profits?
4. When and where do costs and benefits accrue?
5. What inputs does the experiment require?
6. When do products emerge?
7. How long do products exist?
8. What maintenance or operation costs exist?
9. What happens after the experiment ends?

social and political Equity

1. Who does the experiment impact?
   Who are the direct and indirect stakeholders?
2. How does the experiment benefit or harm various stakeholders?
3. To what extent do stakeholders benefit equally? Pay equally?
4. Does the experiment create any inequities?
5. Consider various stakeholders' locations, communities, access to resources, economic power, knowledge, skills, and political power.

Figure 2. Leading questions to prompt 4E Sustainability Analysis.

Exposing students to several sustainability definitions can ease the resistance some feel when asked to connect technical engineering concepts to seemingly unrelated topics. Some students feel a similar resistance when expected to practice high quality technical communication and critical thinking skills along with more technical problem solving. Using the synergies between technical communication, critical thinking, sustainability analysis, and systems thinking can help students solve technical problems. Perhaps, teaching students to dispel the imagined barrier between engineering and sustainability can similarly improve their problem solving skills.

Assignment Mechanics

For Students

The appendix and http://tinyurl.com/EE306-Sust[12] contain the sample sustainability analysis assignment prompt and a rubric used during Fall 2010. The prompt introduces general sustainability definitions,[6-10] lists Commoner's laws of ecology,[13] has a brief bibliography, and refers students to a wiki established to support efforts to teach sustainability issues associated with integrated circuits, http://sustainability-and-ICs.pbworks.com/.[11] As mentioned in the *4E Sustainability Analysis* section, the wiki also contains sustainability analyses written by students during prior courses. The prompt asks students to **explain how a course experiment or applications related to the experiment contribute to or prevent sustainability, based on the 4E Sustainability Analysis and the green engineering design principles**.[14] Assignment submission directions have students post their work online as a webpage or on a wiki and send to instructor email messages formatted to permit semi-automatic handling explained in the following instructor section. Students then evaluate the assignments submitted by two of their colleagues using a moderately detailed rubric, with the average score recorded as 5% of the course grade.

Because the course devotes most available class time to meeting its non-sustainability learning outcomes, the sustainability analysis teaching strategy has to consume minimal class time. During fall quarter 2010, the instructor spent about 20 minutes in class discussing fossil fuel and renewable energy issues as a detour from the required photodiode, solar cell, and LED course topics. An additional ten minutes went to introduce the analysis assignment and the 4E Sustainability Analysis questions listed in Figure 2. Enough readings and videos posted on the course Blackboard™ website ensure students can find a few that interest them sufficiently to inform their assignment.[15] Spending this little in-class time on content delivery reduces only minimally, by less than 3%, the amount of time devoted to traditional course topics.

After exploring the wiki[11] and consulting the rubric,[12] students seem to find much of the assignment self-explanatory. In order to handle misgivings some students have about posting their work online in a way that identifies them by name, the author offers them the option of submitting the assignment using a pseudonym and temporary email address. Students who have never posted a web page or wiki online require minimal instruction. Since wiki authoring tends to require a shorter learning curve, the author refers them to search the web for free wiki resources, so students find and adopt the authoring technology. Compared to a few years ago, when the author required students to post their work directly as web pages,[16] fewer students have trouble working with the wikis.

For Instructors

Evaluating dozens, if not hundreds, of student sustainability essays poses a heavy burden on an instructor's time and energy, so this work relies on student peer review. Aside from reducing how much time an instructor must invest in reading and commenting student assignments, peer review allows students to learn best practices directly from their peers. Learning may also happen when students observe less-than-best practices.

Ideally, an instructor should carefully read all the analysis reports submitted. Since doing so would take too long, the author scanned each report briefly and each reviewer report, paying most attention to reports in one of the following categories:

- One or more reviewer(s) assign full credit for discussing all four "E" topics, but the report doesn't discuss all four.
- One or more reviewer(s) assign full credit for covering the green engineering design principles, but the report does not address green engineering principles.
- The report lists no bibliographic references, but the reviewer does not notice.
- Reviewer reports have no comments entered.
- The two reviewer scores differ by more than 5 points.

Perhaps emphasizing the need to fill in all blue shaded cells in the rubric would reduce how many students skip entering comments upon first submitting a peer review. Having reviewers reconsider and resubmit their reviews in these cases may have slightly improved the calibrations.

This work refers to two tools to somewhat lessen the instructor's workload:

1. Peer Grade Dashboard on http://courseware.ee.calpoly.edu/~dbraun/PGD/PGD.html[17], or
2. CPR (Calibrated Peer Review) on http://cpr.molsci.ucla.edu/[18]

The author wrote the Peer Grade Dashboard tool to automate assignment administration. Specifically, the tool assists with assigning peer reviewers, collating scores and comments received from peer reviewers, and tasks associated with assignment email communications. The open source Peer Grade Dashboard tool uses the Thunderbird Email Software and Microsoft Excel Software. This tool may make sense for an instructor with programming ability who desires to tailor the process and can tolerate buggy software. Instructors who prefer a more professional tool might wish to use the Calibrated Peer Review tool from UCLA.[18] The author hasn't classroom tested the Calibrated Peer Review tool. Assisted by the Peer Grade Dashboard tool, assignment administration required less than four hours for 72 students, much less than the approximately 15 minutes per paper required when the instructor assessed similar assignments during prior classes. The proposed approach certainly demands less instructor time than the time devoted to reading sustainability analysis sections in weekly lab reports.[2]

The next section discusses results from direct assessments employed to measure sustainability analysis skills.

Assessment Results

The assessment uses two questions to measure if students can define sustainability and analyze sustainability issues associated with one lab experiment. The assessment also measures if exposure to the proposed sustainability teaching strategy makes any difference in students' performance on the assessment. Fig. 3 contains the sustainability assessment questions and the rubric designed to score student responses. At the risk of redundancy, please distinguish the Fig. 3 assessment instrument this section contains from the class assignment rubric described in the previous Assignment Mechanics section and found in the appendix.

1. **Write one or two definitions of sustainability.**
   a. 0 points if misses sustainability all together
   b. 1 point for a vague definition related to sustainability
   c. 2 points for a clear definition close to either the Brundtland definition, Euston and Gibson definition, McDonough & Braungart definition, or another accepted definition

Brundtland	Sustainability allows people to meet the needs of the present generation without compromising the ability of future generations to meet their own needs.
Euston & Gibson	Sustainability describes a condition in which natural systems and social systems survive and thrive together indefinitely
McDonough & Braungart	"Design systems that love all the children of all species for all time" or "The goal is a delightfully diverse, safe, healthy, and just world, with clean air, soil, water, and power, economically, equitably, ecologically, and elegantly enjoyed."

   d. 3 points for a clear definition incorporating more than one accepted definition

2. **Select one EE 34x experiment and explain how it relates to sustainability issues.**
   a. 1 point for each connection to energy, economic, environmental, social and political equity, and ethics
   b. 1 point for each connection to a law of ecology
      - Everything connects to everything else
      - Everything must go somewhere
      - Nature knows best and bats last
      - There is no such thing as a free lunch
   c. 1 point for weaving in more than one EE 34x experiment

Figure 3. Sustainability assessment and scoring rubric.[6,8,9,16] Questions appear in bold type, and the rubric follows each question. EE 34x refers to EE 346 for the F10 assessment and EE 347 for the W08 and S08 assessments.

Course scheduling conveniently sets up experimental and control cohorts. Course offerings consist of multiple lecture sections containing 20-40 students and lab sections containing <25 students. Students completed the assessment in their lecture sections at the end of Winter 2008, Spring 2008, and Fall 2010 as "pop" quizzes. A score depending on effort contributed modestly to the course grade (<2%), but the description below only reports the score obtained using the rubric of Fig. 3. During both quarters in 2008, the author taught all lecture sections and three lab sections. During Fall 2010, the author taught only two of five lecture sections and one lab section. The author required students to complete the required sustainability analyses in their lab reports, with the analyses counting for up to 10% of a weekly lab report score. Other instructors taught the remaining lab sections and did not require students to complete the sustainability analyses. "Experimental" cohorts contain students who performed the sustainability analyses in lecture sections, lab sections, or both lecture and lab sections. "Control" cohorts contain students who did not perform sustainability analyses in either their lecture or their lab sections.

Fig. 4 presents the assessment results as a box plot. The boxes compare sustainability assessment scores for "Experimental" and "Control" groups during three quarters. The average scores for the "Experimental" groups (5.29, 4.40, and 4.17) exceed the average score for the "Control" group (2.54). Differences in average scores between experimental groups and the control group are statistically significant (P=0.001 for "F10 Lecture + Lab," P=0.000 for "F10 Lecture Only", and P=0.000 for "W08,S08 Lab Only"). Large effect sizes result (1.29, 0.88, and 0.69) even though each quarter's data have large standard deviations (>1.3). Differences in average scores between experimental groups performing sustainability analysis class assignments are not statistically

significant (0.150 for “F10 Lecture + Lab” vs. “F10 Lecture Only,” 0.087 for “F10 Lecture + Lab” vs. “W08,S08 Lab Only,” and 0.460 for “F10 Lecture Only” vs. “W08,S08 Lab Only”). On average, students completing the sustainability analyses assignment in lecture or lab courses score higher on the sustainability assessment, indicating more advanced conceptual development.[19]

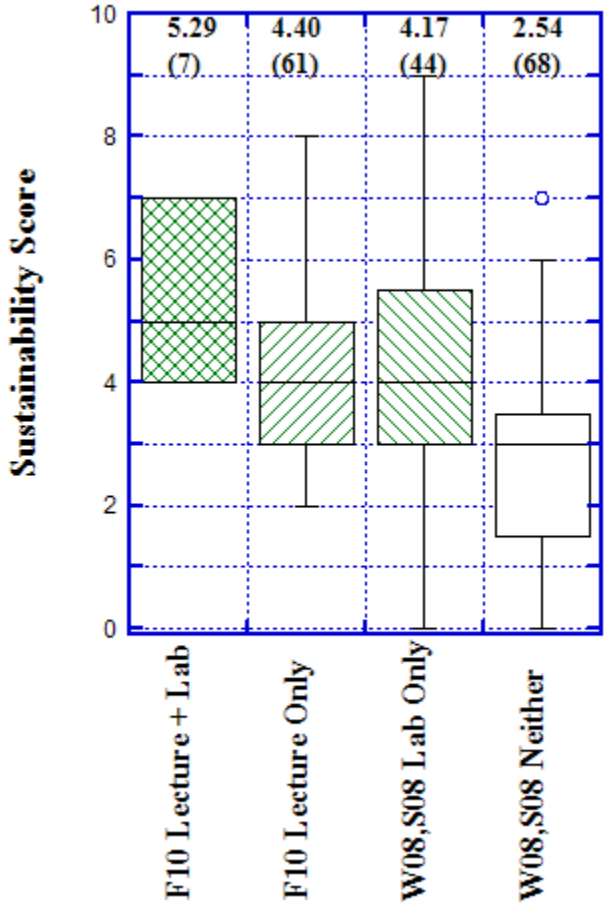

Figure 4. Sustainability analysis assessment results. The box plots compare experimental cohorts (hatched) with a control cohort for the assessments administered during three quarters: Fall 2010 (F10), Spring 2008 (S08), and Winter 2008 (W08). The “F10 Lecture + Lab” experimental cohort contains students whose lecture section performed the proposed sustainability analyses AND whose lab sections performed weekly sustainability analyses. The “F10 Lecture Only” experimental cohort contains students whose lecture section performed the single proposed sustainability analyses. The “W08,S08 Lab Only” experimental cohort contains students whose lab sections performed weekly sustainability analyses. The “W08,S08 Neither” control cohort contains students who performed sustainability analysis in neither lecture nor lab sections. Numerical values indicate average scores for each cohort with sample size in parentheses.

Conclusion

Following several attempts to teach multidisciplinary sustainability analysis using repeated assignments within electronics **laboratory** courses,[2] this work compares the effectiveness of having students complete just one sustainability analysis writing assignment during an

electronics **lecture** course. This work has presented sustainability analysis learning objectives, information resources to help students achieve the learning objectives, assignment mechanics, tools to facilitate assignment peer review, and assessment results. Direct assessment results imply the single writing assignment in the lecture class produces similar learning to weekly writing assignments in lab, though requiring less instructor time. Students completing both the lecture and lab sustainability analyses produce higher average assessment scores, but the small sample size prevents drawing a statistically significant conclusion. Whether implemented in lecture or lab, the proposed sustainability analysis assignment produces statistically significant higher assessment scores compared to a control group not having performed the assignment.

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Bibliography

1. ABET Board of Directors, Criteria for accrediting engineering programs. Baltimore MD: ABET, 2007. Available: http://www.abet.org/Linked Documents-UPDATE/Criteria and PP/E001 08-09 EAC Criteria 12-04-07.pdf [Accessed January 16, 2009]
2. D. Braun, "Teaching Sustainability Analysis in Electrical Engineering Lab Courses," *IEEE Transactions on Education*, vol. 53 no. 2, pp. 243-247, 2010
3. D. Braun, "EE 306 Learning Objectives," Available: http://courseware.ee.calpoly.edu/~dbraun/courses/courseinfo/ee306/EE306LearningObjectivesF10.html. [Accessed December 27, 2010]. Email dbraun@calpoly.edu for password.
4. Joint Task Force on Computer Engineering Curricula (IEEE-CS and ACM), *Computer Engineering 2004: Curriculum Guidelines for Undergraduate Degree Programs in Computer Engineering*, Dec. 12, 2004, Available: http://www.eng.auburn.edu/ece/CCCE/CCCE-FinalReport-2004Dec12.pdf. [Accessed January 16, 2009]. Electronics areas CE-ELE1 through CE-ELE3, CE-ELE5, CE-ELE10, and CE-ELE12; pp. A.38-A.42
5. D. Braun, "EE 346," Available: http://courseware.ee.calpoly.edu/~dbraun/courses/ee306/ee346.html. [Accessed September 20, 2010].
6. S. R. Euston and W. E. Gibson, "The Ethic of Sustainability," *Earth Ethics*, vol. 6, pp. 5-7, 1995.
7. G. Van de Kerk and A. R. Manuel, "A comprehensive index for a sustainable society: The SSI — the Sustainable Society Index," *Ecol. Econ.*, vol. 66, no. 2-3, pp. 228-242, 2008.
8. W. McDonough, as quoted in "Waste = Food (An inspiring documentary on the Cradle to Cradle design concept)" 2006 [Podcast television program] Directed by R. van Hattum. The Netherlands: VPRO. Available: http://video.google.com/videoplay?docid=-3058533428492266222. [Accessed January 16, 2009].
9. The World Commission on Environment and Development, *Our Common Future*, chaired by Norwegian Prime-Minister Gro Harlem Brundtland, 1987.
10. *Global Climate Change: Linking Energy, Environment, Economy, and Equity*, J. C. White, Ed. New York: Plenum Press, 1992.
11. D. Braun and Cal Poly Electrical and Computer Engineering Students, "Cal Poly's wiki for Sustainability in Integrated Circuits," Available: http://sustainability-and-ICs.pbworks.com/. [Accessed December 27, 2010].
12. D. Braun, "EE 306 Sustainability Analysis Assignment," Available: http://tinyurl.com/EE306-Sust and http://courseware.ee.calpoly.edu/~dbraun/courses/ee306/SustainabilityAnalysis.html. [Accessed December 27, 2010]
13. B. Commoner, *The Closing Circle: Nature, Man, and Technology.* New York: Alfred A. Knopf, 1972, pp. 16-24.
14. D. Braun, "EE 306 Sustainability Analysis," Available: http://tinyurl.com/EE306-Sust. [Accessed December 21, 2010].

15. D. Braun, “EE 347 Sustainability References,” Available: http://courseware.ee.calpoly.edu/~dbraun/courses/ee307/EE347-Sust-ICs-References.html. [Accessed January 16, 2009]
16. D. Braun, “Web Based Design and Analysis Projects for a Junior Level Integrated Circuit Course”, Paper AC 2007-922, *2007 ASEE Annual Convention*, Honolulu, Hawaii, Available: http://soa.asee.org/paper/conference/paper-view.cfm?id=4184 [Accessed December 27, 2010]
17. D. Braun, “Peer Grade Dashboard Tool,” Available: http://courseware.ee.calpoly.edu/~dbraun/PGD/PGD.html. [Accessed January 16, 2011]
18. Orville L. Chapman & Michael A. Fiore, *Calibrated Peer Review™ A Writing and Critical Thinking Instructional Tool*, 2001, http://cpr.molsci.ucla.edu/. White Paper Available: http://cpr.molsci.ucla.edu/cpr/resources/documents/misc/CPR_White_Paper.pdf [Accessed: January 10, 2011]
19. A. L. Carew; C. A. Mitchell, “Characterizing undergraduate engineering students' understanding of sustainability,” *Eur. J. Eng. Educ.*, vol. 27, no. 4, pp. 349–361, 2002.

EE 306	**SUSTAINABILITY ANALYSIS ASSIGNMENT**	Braun

This assignment practices analyzing sustainability issues associated with an electronics design idea and its applications.

Read about sustainability on http://sustainability-and-ics.pbworks.com/ [1]. Sustainability describes a condition in which natural systems and social systems survive and thrive together indefinitely [2]. A sustainable condition allows people to meet the needs of the present without compromising the ability of future generations to meet their own needs [3]. Because humanity now consumes and pollutes the Earth's resources faster than natural and human systems can replenish and clean them, we do not currently live in a sustainable manner [4]. Consider Commoner's laws of ecology, which sound unsurprisingly similar to laws of physics:

- ***Everything connects to everything else***
- ***Everything must go somewhere***
- ***Nature knows best and bats last***
- ***There is no such thing as a free lunch* [5].**

Analyze sustainability issues associated directly or indirectly with your EE 346 experiment 4, 5, 7, or 8.

- Explain how your EE 346 experiment or applications related to the experiment contribute to or prevent sustainability [6]. Reference [7] and others on Blackboard™ [8]-[20] provide helpful information.
- Consider issues related to Energy, Environment, Economics, and social or political Equity, four "E"s of sustainability.
- Explain to what extent the design embodies the green engineering design principles[21]
  1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
  2. Conserve and improve natural ecosystems while protecting human health and well-being.
  3. Use life-cycle thinking in all engineering activities.
  4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
  5. Minimize depletion of natural resources.
  6. Strive to prevent waste.
  7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.
  8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.
  9. Actively engage communities and stakeholders in development of engineering solutions.

Post your **sustainability analysis** as a wiki or webpage, and email your url before class before class on _____. Your wiki should clearly reference your design idea. Hint: read the assignment rubric and use the paramedic method.

To submit your analysis to your instructor, send an email with the following content:

1. To: dbraun@calpoly.edu
2. Subject: EE 306F10 Sustainability Analysis for username@calpoly.edu
3. Message first line: Your last name
4. Message second line: Your first name
5. Message third line: username@calpoly.edu
6. Message fourth line: wiki or webpage url
7. Message additional lines: optional text, but no images or attachments

Where "username@calpoly.edu" appears above, please insert your Cal Poly email address, e.g. dbraun@calpoly.edu. Please follow the above formatting EXACTLY. Your instructor will redistribute your email message automatically to a few

of your class colleagues for their assessment of your work.

Submit evaluation forms for the two sustainability analyses your instructor assigned you to evaluate before class on _____. Your email should use the following format:

1. To: dbraun@calpoly.edu
2. Subject: EE 306F10 Sustainability Analysis for username@calpoly.edu
3. Message first line: Your last name
4. Message second line: Your first name
5. Message third line: username@calpoly.edu
6. Message additional lines: optional text, but no images
7. Attachments: Attach your two evaluation form files to the email message. Please use the same evaluation form sent by your instructor. Do not change the filenames or file format.

The above assignment describes baseline requirements. Feel free to go beyond this guideline and consider a more in-depth or creative analysis. Here are a few illustrative examples:

- Perform a quantitative Life Cycle Analysis, not just qualitative. [22, 23]
- Explain how to make the design idea function more sustainably.

REFERENCES

1. D. Braun and Cal Poly Electrical and Computer Engineering Students, "Cal Poly's wiki for Sustainability in Integrated Circuits," Available: http://sustainability-and-ics.pbworks.com/. Accessed January 16, 2009].
2. S. R. Euston and W. E. Gibson, "The Ethic of Sustainability," *Earth Ethics* **6**, 1995 p. 5-7. Available: http://www.iisd.org/sd/principle.asp?pid=31&display=1. [Accessed Jan. 16, 2009].
3. The World Commission on Environment and Development, *Our Common Future*, chaired by Norwegian Prime-Minister Gro Harlem Brundtland, 1987.
4. Millennium Ecosystem Assessment, *Ecosystems and Human Well-being: Current State and Trends, Volume 1,* Eds. R. Hassan, R. Scholes, & N. Ash, Washington, D.C.: Island Press, 2005, p. 2-76, 827-838. "MA Findings Animated slides," Available: http://www.maweb.org/en/SlidePresentations.aspx, [Accessed Feb. 15, 2011]
5. B. Commoner, *The Closing Circle: Nature, Man, and Technology*. New York: Alfred A. Knopf, 1972, pp. 16-24.
6. P. Hawken, A. Lovins, and L.H. Lovins, *Natural Capitalism*. New York: Little, Brown and Company, 1999, pp. 49-50, 57-58, 121, 153-154. Available: http://www.natcap.org/images/other/NCchapter3.pdf [Accessed March 22, 2006].
7. E. Williams, "Environmental impacts in the production of personal computers," in *Computers and the Environment: Understanding and Managing Their Impacts*, R. Kuehr and E. Williams, Eds. Dordrecht: Kluwer, 2003, pp. 41-72.
8. G. Van de Kerk and A. R. Manuel, "A comprehensive index for a sustainable society: The SSI — the Sustainable Society Index," *Ecological Economics* vol. 66 no. 2-3, pp. 228-242, 2008.
9. Olaitan Ojuroye, as cited in Paul L. Bishop, *Pollution Prevention: Fundamentals and Practice* Long Grove, IL: Waveland, 2004, p. 584.
10. W. McDonough, as quoted in "Waste = Food (An inspiring documentary on the Cradle to Cradle design concept)" 2006 [Podcast television program] Directed by R. van Hattum. The Netherlands: VPRO. Available: http://video.google.com/videoplay?docid=-3058533428492266222. [Accessed September 1, 2008]; William McDonough & Michael Braungart, *Cradle To Cradle*, New York: North Point Press, 2002.
11. Bruce McConnel, "IBM Pioneers Process to Turn Waste into Solar Energy," IBM Press Release Oct. 30, 2007, Available: http://www-03.ibm.com/press/us/en/pressrelease/22504.wss. [Accessed February 15, 2011]
12. S. Gaudin, "Intel's New 45nm Penryn Plant Goes Green," *Computerworld*, October 30, 2007. Available: http://www.pcworld.com/article/id,139089-c,intel/article.html. [Accessed: October 30, 2007].
13. M. Michalovic, " Tantalum, Congo, and Your Cell Phone," *ChemMatters*, October 2007, pp. 16-18.
14. A. Koehler and C. Som, "Effects of Pervasive Computing on Sustainable Development," *IEEE Technology and Society Magazine*, 2005 p. 15-23. Available: http://www.ieeessit.org/technology_and_society/free_sample_article.asp?ArticleID=1. [Accessed: October 30, 2007].
15. Jeff Johnson, "A Tsunami of Electronic Waste," *Chemical & Engineering News*, vol. 86 no. 21, 2008, pp. 32-33, Available: http://pubs.acs.org/cen/government/86/8621gov1.html [Accessed June 3, 2008].
16. P. Stamets, "6 ways mushrooms can save the world," TED Talk, March 2008. [Podcast lecture] Available: http://www.ted.com/index.php/talks/paul_stamets_on_6_ways_mushrooms_can_save_the_world.html. [Accessed: September 1, 2008]

17. P. Senge, *The Fifth Discipline*, New York: Doubleday, 1990, pp. 373-391.
18. P. Ehrlich & A. Ehrlich, *One with Nineveh: Politics, Consumption, and the Human Future*, Washington DC: Island Press, 2005, pp. 69, 261-262, 335.
19. University Leaders for a Sustainable Future, *The Talloires Declaration*, 2001, Available: http://www.ulsf.org/programs_talloires_td.html. [Accessed Sept. 29, 2006]
20. G. Hardin, "The Tragedy of the Commons," *Science* vol. 162 no. 3859, pp. 1243-1248, 1968. Available: http://www.sciencemag.org/sciext/sotp/commons.dtl. [Accessed: March 22, 2006]
21. Developed by more than 65 engineers and scientists at the Green Engineering: Defining the Principles Conference, held in Sandestin, Florida in May of 2003. The preliminary principles forged at this multidisciplinary conference are intended for engineers to use as guidance in the design or redesign of products and processes within the constraints dictated by business, government, and society such as cost, safety, performance and environmental impact. From U.S. EPA, *What is Green Engineering*, Sept. 13, 2007, Available: www.epa.gov/oppt/greenengineering/pubs/whats_ge.html. [Accessed: Jan. 16, 2009]
22. C. T. Hendrickson, L. B. Lave, & H.S. Matthews, *Environmental Life Cycle Assessment of Goods and Services An Input-Output Approach*, Washington DC: Resources for the Future, 2006
23. Carnegie Mellon University Green Design Institute. (2008) Economic Input-Output Life Cycle Assessment (EIO-LCA), US 2002 Industry Benchmark model [Internet], Available: http://www.eiolca.net [Accessed: September 15, 2010]

EE 306 Sustainability Analysis Evaluation Rubric Braun

Author name:
Author User Name:
Analysis url:
Evaluator name:
Evaluator User Name:

Topic	**Points Possible**	**Points Actual**
Explain how your design or applications related to the design contribute to or prevent sustainability. References [1]-[23] provide helpful information.	10	
Consider issues related to *Energy*, *Environment*, *Economics*, and social or political *Equity*, four "E"s of sustainability.	5	
Explain to what extent the design embodies the green engineering design principles[21] 1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools. 2. Conserve and improve natural ecosystems while protecting human health and well-being. 3. Use life-cycle thinking in all engineering activities. 4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible. 5. Minimize depletion of natural resources. 6. Strive to prevent waste. 7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures. 8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability. 9. Actively engage communities and stakeholders in development of engineering solutions.	5	
Evaluator could access your **sustainability analysis** url on their first attempt.	2	
TLCCC (Technical and Learning Content, Completeness, Commentary)	4	
PPLGS (Presentation, Professionalism, Legibility, Grammar, Spelling)	4	
Creativity		
Extras (+2 for Using the Paramedic Method with zero lard factor)		
Total	30	

Negative Points	-3	-2	-1	0	**Points**
Evidence, Reasoning & Critical Thinking	Poor evidence, reasoning or critical thinking.	More evidence, reasoning, or critical thinking missing.	A lack of evidence, reasoning, or critical thinking.	Each topic sentence supported by evidence, reasoning, and critical thinking.	
Clarity, Grammar & Spelling	More than four grammar and/or spelling errors	Three or four grammar and/or spelling errors	One or two grammar or spelling errors	All grammar and spelling are correct	
References	No references	Too few references or more than two citation errors.	Enough references, some cited incorrectly	Enough references, cited completely & correctly. Has authors	

Comments: