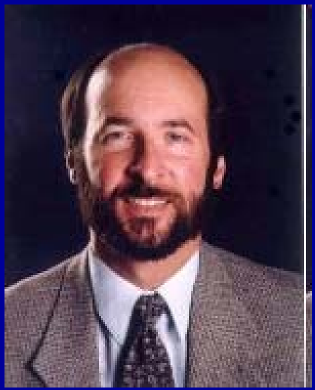
Teaching Sustainability in Cal Poly Electrical and Computer Engineering Programs

- Approaches for lower division, upper division and grad courses
- Opportunities for SLOs



David Braun, Art MacCarley, John Oliver

Electrical & Computer Engineering

California Polytechnic State University, San Luis Obispo

June 22, 2009

EE 111 – Freshman Seminar (first course taken by EE freshmen)

One week devoted to making new students aware of the importance of electrical engineers to the solution of environmental problems:
“A New Role for Engineers, Scientists and Hands-on Problem Solvers”

• Just as technology played a major role in creating the problem, people look to technology to solve the problem.

• Reality: Even those of us that are deeply concerned secretly hope that there is a technical solution out there that will allow use to continue our present lifestyle.

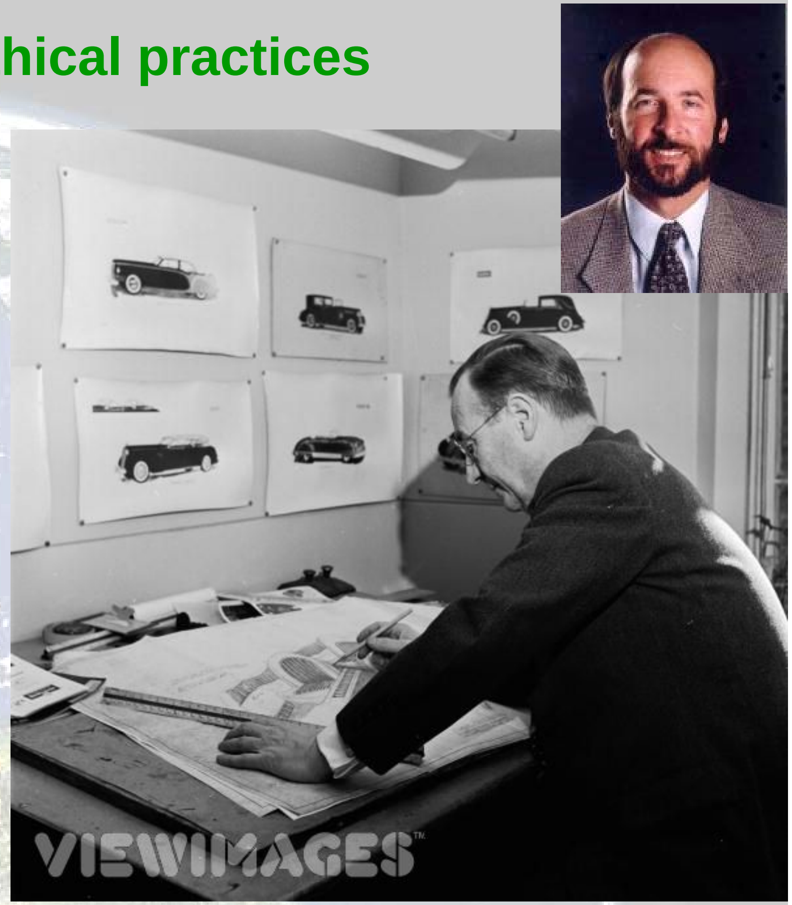
• Technology comes from the minds and hands of scientists and engineers. We play a very special role not only in the problem, but the potential solutions to it.

• Since we have always come through in past challenges, it’s expected of us.

• While the complete issues are vastly larger and more complex than just the technical problems, we still possess a disproportionate responsibility for shaping the destiny of the planet.

http://www.eia.doe.gov/oiaf/ieo/figure_11.html
http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html

Increasing awareness: a new code for ethical practices



Old:

- I just create or work on the technologies. I am not responsible for their use.
  "I just do what I'm paid to do."
- Financial or social self-interest
  "Gotta have that Hummer"
- Intellectual self-interest
  "Research for the sake of grant funding"

Note that these attitudes are only obliquely addressed in current codes of ethics: see http://www.nspe.org/Ethics/CodeofEthics/index.html or http://www.ieee.org/portal/pages/iportals/aboutus/ethics/code.html

New:

- I have an ethical obligation to use our knowledge and skills for the betterment of the planet.

- I am willing to take responsibility for what I create.

- Look beyond the narrow focus of any educational discipline; see the big picture.

NSPE Code of Ethics for Engineers

2. Engineers shall at all times strive to serve the public interest.

2.E. Engineers are encouraged to adhere to the principles of sustainable development[1] in order to protect the environment for future generations.

http://www.nspe.org/Ethics/CodeofEthics/index.html

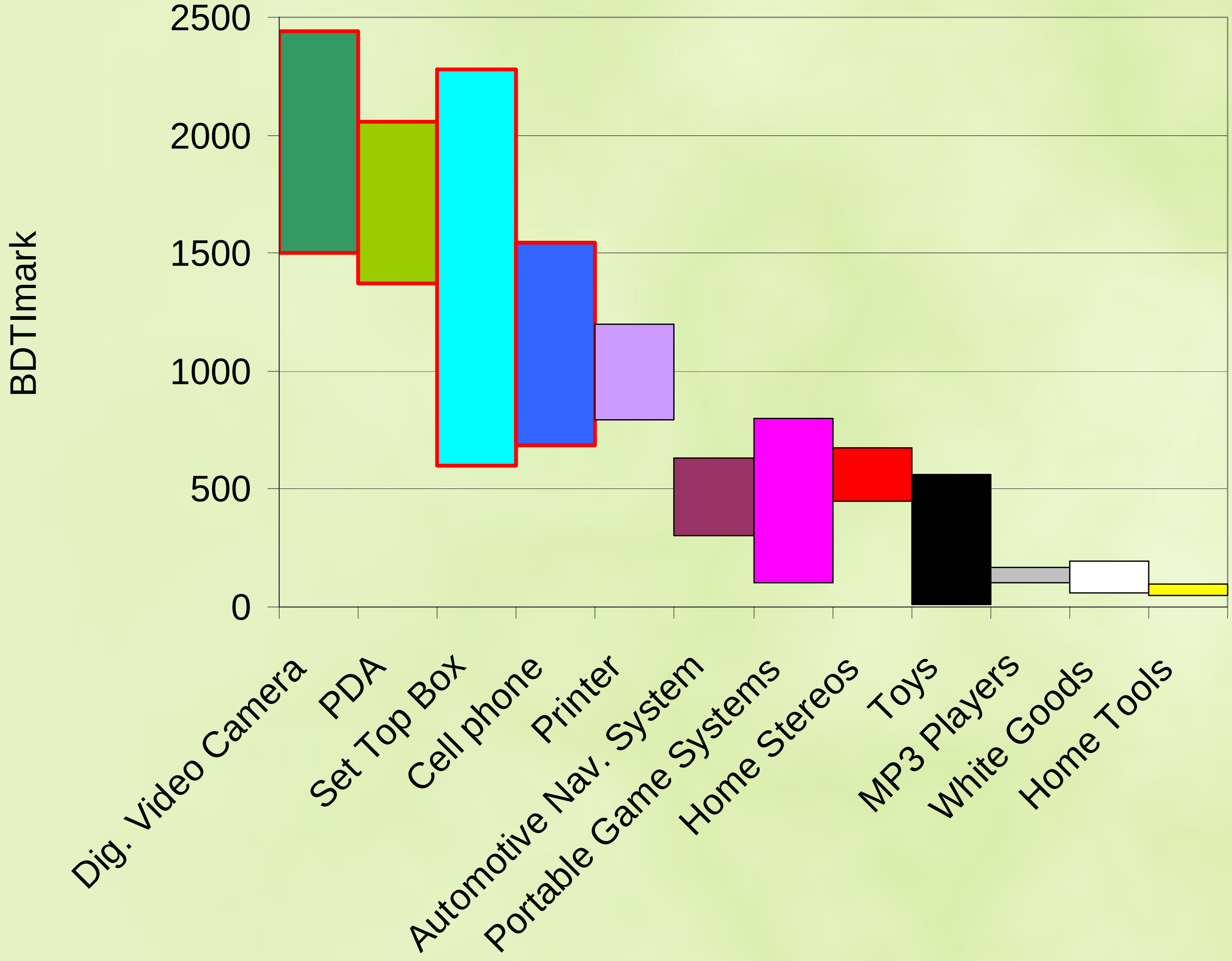
Manufacturing Costs of Microprocessors

- 2 GJ of energy to manufacture a 300 mm^2 wafer
  - Roughly the energy in 200 gallons of gasoline
  - 34 MJ of energy required to manufacture a 100 mm^2 Processor (includes assembly)[1]

- Processors are everywhere!:
  - Over 1.7B Cellular phones in use
  - Over 58M iPods manufactured
  - Over 21M Nintendo DS systems manufactured
- 1.7B Cellular Phones ~ 1.7B 20mm^2 processors
  - 18,700 Tera Joules!
  - ~500 pounds of Uranium-235
  - ~150 M gallons of gasoline
    - Yearly consumption of the United States

[1] "The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices", Eric D. Williams, Robert U. Ayers and Miriam Heller, *Environ. Sci. Technol.*, 2002, 36 (24), pp 5504–5510

Idea: Processor Re-Use Food-Chain



Idea: Processor Re-Use Food-Chain

- Processors are energy-intensive to manufacture
- Re-use processors from old devices in, “next generation” devices
  - Next gen. devices should have equal or lower computational demand
- Creates a processor ***“food-chain”***
  - Extends the lifecycle of the processor
  - Need to balance with in-use consumption
  - Life Cycle Analysis (LCA) based on energy

Teaching and Assessing Multidisciplinary Sustainability Analysis

- Sustainability Confronts the Technical Mindset
- Assessment results
- Weekly Assignments

http://digitalcommons.calpoly.edu/susconf/52/

http://sustainability-and-ICs.pbwiki.com/

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CAL POLY

Aug. 1, 2008

How to Prepare EE 347 Lab Reports

First A. Author, *Member, IEEE*, Second B. Author, Jr., and David Braun, *Senior Member, IEEE*

***First Author's Abstract*—Use these guidelines to prepare Cal Poly lab reports based on author instructions for IEEE TRANSACTIONS and JOURNALS. This work describes required lab report content and provides procedures for preparing and submitting lab reports. This document provides a template for lab reports to teach students how to document their experimental work, analysis, and learning in a manner conducive of the quality required by the IEEE in its professional JOURNALS and TRANSACTIONS. This document appears online at http://www.ee.calpoly.edu/~dbraun/courses/IEEE-EE347-Reports.doc. It derives from the original version at http://www.ieee.org/web/publications/authors/transjnl/index.html with the authors' commentary interspersed into the original directions.**

***Second Author's Abstract*—Use this document as a template, if you use Microsoft *Word*. Otherwise, use this document as an instruction set. Define all symbols used in the abstract. Do not cite references in the abstract. Do not delete the blank line immediately above the abstract; it sets the footnote at the bottom of this column.**

***Index Terms*—Circuit simulation, digital integrated circuits, professional communication, semiconductor devices, writing. About four key words or phrases in alphabetical order, separated by commas. Suggested keywords appear in the list at http://www.ieee.org/organizations/pubs/ani_prod/keywrd98.txt.**

I. Introduction and Learning Objectives

THIS section provides context for the experiment, defines the experimental topics, and explains the learning objectives. Write this section before class.

Cal Poly EE laboratory courses typically prepare students to meet at least ABET outcomes 3a, 3b, 3c, 3e, 3g, and 3k:
(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability 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
(e) an ability to identify, formulate, and solve engineering problems
(g) an ability to communicate effectively

II. Sustainability Issues

Use this section to analyze sustainability issues associated directly or indirectly with your experiment. 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]. It might prove helpful to 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].

Explain how experiment topics or applications related to the experiment foster or prevent sustainability [6]. Reference [7] and others on Blackboard™ provide helpful information. Consider issues related to *Energy*, *Environment*, *Economics*, and social or political *Equity*, four "E"s of sustainability.

III. Troubleshooting

Document any troubleshooting completely, both in your lab notebook and in this section of your lab report. If something goes wrong, explain your methodical approach to resolving the problem. Document hypotheses developed to explain any difficulties, explain how you tested each hypothesis, and document any fixes implemented.

IV. Post-Lab Questions

Answer all post-lab questions. The EE 347 lab manual hides post-lab questions in sneaky places so read carefully.

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REFERENCES

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. 827-838. "MA Findings Animated slides," Available: http://www.millenniumassessment.org/en/SlidePresentations.aspx, [Accessed Jan. 26, 2008]
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. Available: http://www.natcap.org/images/other/NCchapter3.pdf [Accessed March 22, 2006].

EE 413 – Advanced Electronic Design

nalysis, time
ry. Prerequisite:
listed as

EE 413 Advanced Electronic Design (4)

Advanced design of electronic circuits and subsystems. Sustainability. Design as a process. Implementation of specific design projects. Teamwork. Automated test using GPIB instruments. 3 lectures, 1 laboratory. Prerequisite: CSC 101, EE 409&449.

2009-2011 Cal Poly Catalog

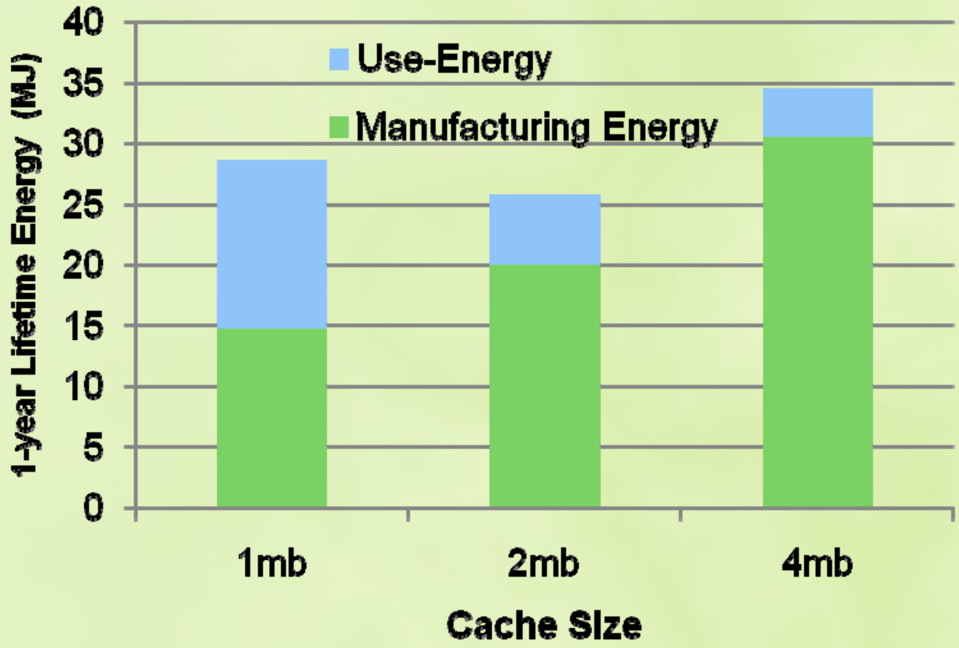
Cal Poly Catalog 2009-2011, http://www.catalog.calpoly.edu/
http://www.catalog.calpoly.edu/2009pubcat/cengr/ee_dept/eecrs2009.pdf, p. 360

Apply green engineering principles to the design process

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.

Current Efforts

- LCA in undergraduate Electrical Engineering classes @ Calpoly
  - Not always best to minimize circuit area
    - Measure performance vs. power consumption vs. area
    - Same processor core, different amounts of cache



EE 514 – Advanced Topics in Automatic Control (Grad Course)

Final project: Apply advanced control theory to environmental policy.

Teams of two, 10-page report and 15-minute PowerPoint presentation.

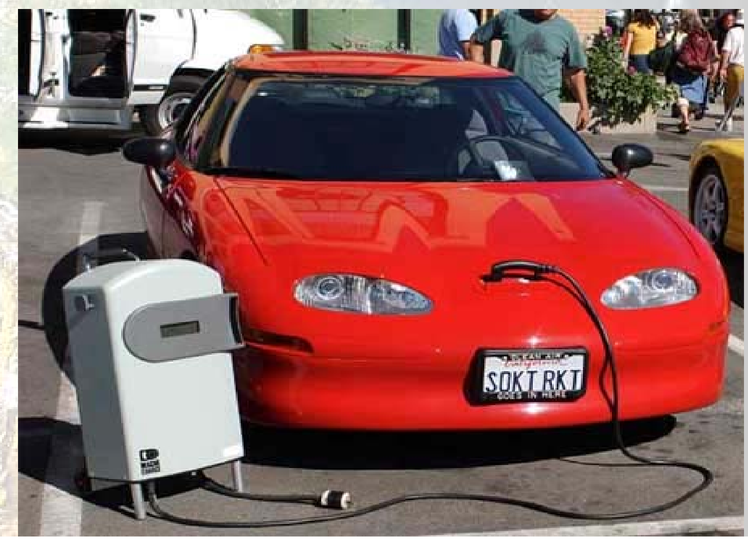
Perform literature search to identify a model of an environmental process affected by human activity, e.g., the thermal balance or the atmospheric carbon balance of the planet, the oxygen content of the oceans. Justify assumptions and simplifications.

Use MATLAB Simulink® to simulate a first-order model of the process.

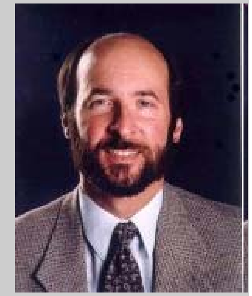
Investigate the use of any three advanced control laws (e.g., optimal control, fuzzy-logic, variable structure control) as the basis of policies that regulate the process, rather than existing crude control laws.

Use these to assess environmental benefit compared with existing laws.

Moral: advanced control theory isn't just for jet engines or robots – we need world leaders that understand these methods – *maybe you*?



Project results and effectiveness assessment:



Seven class projects:

- "Optimal control of Global Temperature through regulation of CO_2"
- Assessment of the effectiveness of the "Gas Guzzler Law", and areas for improvement via improved regulatory strategies."
- "Green conversion: an alterative tax structure for electricity usage".
- "Ramifications of absolute EV mandates" compared with regressive feedback regulation of mobile emitters.
- Feedback control of ocean O_2 via large-scale iron oxide addition.
- Life-cycle product investment for considering environmental impact.
- Ethanol – a closed-loop environmental assessment

Cost functions:

- C_a is an integral of a function (ca) of carbon dioxide emission rates
- C_d is an integral of a function (cd) of temperature rates

$$C_a = \int_{t0}^{tf} c_a(e(t), \dot{e}(t), \ddot{e}(t), t)\, dt$$

where

$$c_a = \left[\left(\frac{1}{r} - r\right)^2 + \tau_1{}^2 \dot{r}^2 + \tau_2{}^4 \ddot{r}^2\right] e^{\left(-\frac{t}{\tau_a}\right)}$$

EE Curriculum

B.S. DEGREE

ELECTRICAL ENGINEERING
Cal Poly, San Luis Obispo

2009-11

FRESHMAN			SOPHOMORE			JUNIOR			SENIOR		
Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter	Spring
Intro to EE EE 111/151[1]	*Fund. Comp. Sci.* CSC 101 (MATH 118 or eqv. w/ ≥C-, & Basic Computer Literacy***)	*Digital Design* EE 129/169 (EE 111, EE 151, CSC 101)	*Electric Circuit Analysis, Lab II & III* EE 211/241 (EE 112 w/ ≥C-, PHYS 133 †, MATH 244 †)	EE 212/242 (MATH 244, EE 211 w/ ≥C-)	*Continuous Time* EE 228 (EE 212 and 242 w/ ≥C-, rcmd. MATH 241)	*Electronics* EE 306/346 (CHEM 124, EE 212 & 242 w/ ≥C-, IME 156 or IME 157 or IME 458, PHYS 211)	EE 307/347 (EE 129 & 169 w/ ≥C-, EE 306 & 346 w/ ≥C-, [illegible])	EE 308/348 (EE 307 & 347 w/ ≥C-, EE 302 & 342 w/ ≥C-)	EE 409/449 (EE 308 & 348 w/ ≥C-, EE 328 & 368 w/ ≥C-, EE 329 w/ ≥C-)		GEB *** [D4]
Electronic Mfg. IME 156 or IME 157		*Electric Circuit Analysis I* EE 112 (MATH 142, sugg. EE 111/151)		*Computer Design* EE 229/269 (EE 129/169 w/ ≥C-)	*Energy Conversion* EE 255/295 (EE 212/242 w/ ≥C-)	*Discrete Time* EE 328/368 (EE 228 w/ ≥C-)	*Control* EE 302/342 (EE 228, EE 255 & 295, Sugg. EE 368)		Technical Elective **	Technical Elective **	Technical Elective **
Analytic Geometry & Calculus MATH 141 *** [B1]	MATH 142 (MATH 141: ≥ C-) [B1]	MATH 143 (MATH 142) [B+]	*Linear Anal. I* MATH 244 (MATH 143 or Instructor Consent)	*Calculus IV* MATH 241 (MATH 143)		*Prob/Random Processes* STAT 350 (EE 228, MATH 241) [B6]	*Communications* EE 314 (STAT 350 w/ ≥ C-)	*Prog Log Microproc-Bsd* EE 329 (EE 307/347 w/ ≥C-, EE 229/269 w/ ≥C-)	*Senior Project* EE 460 (EE 314 w/ ≥C-, EE 335 w/ ≥C-, EE 409&449 †)	EE 461 or 463 (EE 409 & 449, EE 460)	EE 462 or 464 (EE 463) (EE 463 for EE 464 only)
Gen. Chem. CHEM 124 ***	*General Physics* PHYS 141 (MATH 141 w/ ≥C-, MATH 142 †) [B3,B4]	PHYS 133 (PHYS 141, MATH 142) [B+]	PHYS 132 (PHYS 141) [B+]		*Modern Phys.* PHYS 211 (PHYS 132, 133, MATH 241)			*Electromagnetics* EE 335/375 (MATH 241, EE 212 & 242 w/ ≥C-)	EE 402 (EE 335 w/ ≥ C-)	GEB *** [D2]	GEB *** [D3]
ENGL 134 *** [A1]	COMS 101/102 *** [A2]	ENGL 149 (completion of GE area A1 and A2) [A3]	BIO 213/ ENGR 213 (MATH 142, CHEM 124) [B2]	GEB *** [C1]	GEB *** [C2]	GEB *** [C3]	GEB *** [C4]	GEB *** [D1]	Engineering Support *	Engineering Support *	Engineering Support *
16	16	18	16	16	16	16	15	17	17	14	17
										TOTAL:	194

Blue – discussed today, instructor dependent

Red – already require sustainability analysis

Which is NOT one of the 3 most cost effective ways to reduce carbon emissions?

Measure in $ per ton CO_2 saved

A. Coal power plant carbon capture and storage
B. Solar photovoltaic power generation
C. LED lighting in commercial buildings
D. Hybrid cars

National Geographics Carbon Reduction Figures

Figures removed due
to lack of copyright.

Available online at Nat
Geo website

Peter Miller, "Saving Energy Starts at Home," National Geographic, 215(3), March 2009, p. 60-81
http://ngm.nationalgeographic.com/2009/03/energy-conservation/carbon-reduction
http://ngm.nationalgeographic.com/2009/03/energy-conservation/carbon-reduction-costs

Jon Creyts, Anton Derkach, Scott Nyquist, Ken Ostrowski, Jack Stephenson, "Reducing U.S. greenhouse gas emissions: How much at what cost?," November 2007, p. 20, http://www.mckinsey.com/clientservice/ccsi/Costcurves.asp

Teaching Sustainability in Cal Poly Electrical and Computer Engineering Programs

- Approaches for lower division, upper division and grad courses
- Opportunities for SLOs
  - Teach in previously untapped courses
  - Pave the way to curriculum reform

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CAL POLY

June 22, 2009

Cal Poly Academic Senate Adopted Sustainability Learning Objectives (June 2, 2009)

We define sustainability as the ability of the natural systems and social systems to survive and thrive together to meet current and future needs. In order to consider sustainability when making reasoned decisions, all Cal Poly graduates should be able to:

1. Define and apply sustainability principles within their academic programs.
2. Explain how natural, economic, and social systems interact to foster or prevent sustainability.
3. Analyze and explain local, national, and global sustainability using a multidisciplinary approach.
4. Consider sustainability principles while developing personal and professional values.

http://www.calpoly.edu/~acadsen/agendas/08-09_agendas/sa0602.pdf