

# Comparison of Life Cycle Assessment Course Content in the U.S.

Course project report for Life Cycle Assessment for Civil Systems (CEE 506 □ SOS 546)

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## Overview

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Life cycle assessment (LCA) is an important decision support framework for estimating and assessing the environmental impacts attributable to the life cycle of products, services or systems (Rebitzer et. al, 2004). LCA is defined as “compilation and evaluation of inputs, outputs, and potential environmental impacts of a product system through its life cycle” (Finkbeiner et. al, 2006). The LCA framework now appears to be taught extensively in academia possibly due to its prevalence in industry practice and policymaking. A study on teaching LCA in North America, that used 50 courses from 32 institutes from the U.S., showed its popularity at both undergraduate and graduate levels, and across a multitude of disciplines, including engineering, public policy, business, economics, human ecology, and planning (Cooper and Fava, 2000). Cooper and Fava (1999, 2000) mainly focused on student composition, course structures, teaching methods used, teaching resources used, barriers to teaching and student experiences. There are concerns that limitations in textbooks, software, and data make it difficult for an instructor to develop, standardize and teach an LCA course. Similarly, these contribute to difficulties for students to access resources to supplement their learning in LCA. However, there appears to be growing demand for formalized LCA education and for the framework to expand its focus beyond environmental impacts, to explore social and economic domains (Hellweg and Canals, 2014).

## Project Scope

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Towards taking stock of LCA education in the U.S., the goal of this project is to identify, compile, categorize, demonstrate, and share successful teaching epistemologies and tools on LCA, that have been developed by academics in the U.S. We aim to develop the foundations for a resource tool kit and database of knowledge, about lesson plans, learning modules, homework assignments, projects, and specific approaches and examples that are currently used in the teaching and learning of LCA. The geographic scope is limited to select universities in the U.S. but the approach used lends to expansion.

Key outcomes of the curriculum assessment include:

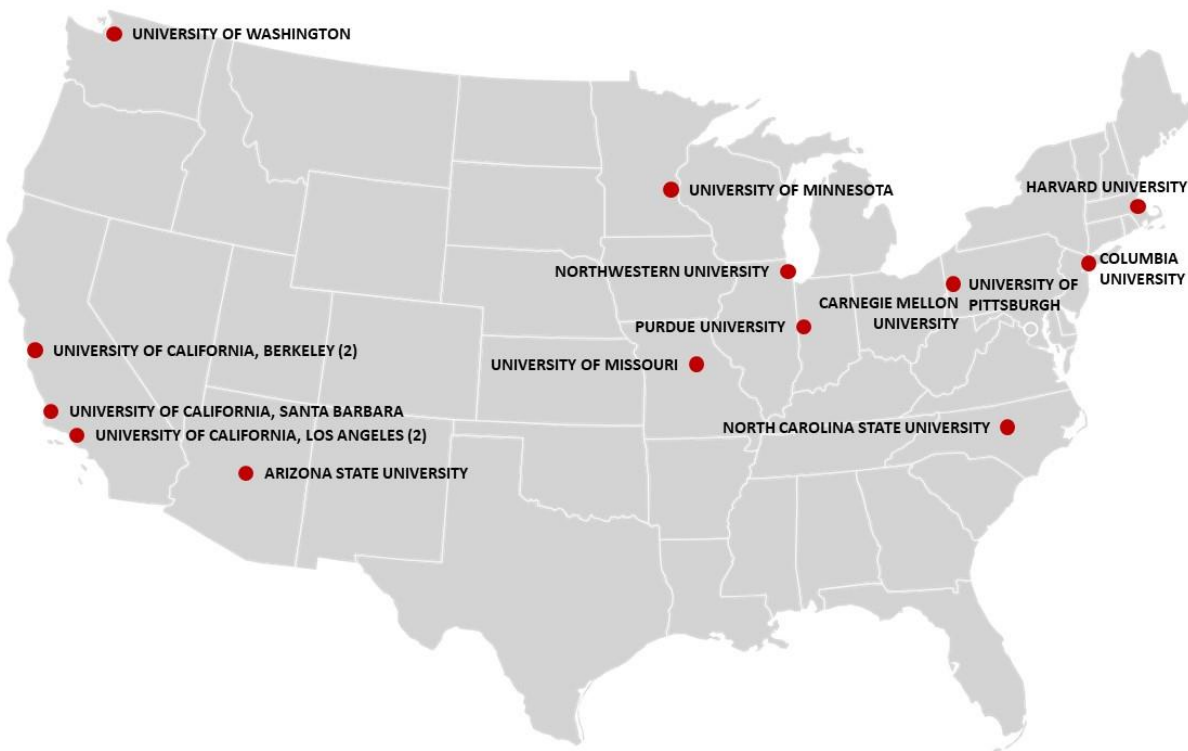
- (i) Studying and assessing trends in course curriculum, theoretical content, specific examples, and applications;
- (ii) Identifying course overlaps and differences among LCA courses in terms of content; and,
- (iii) Developing a database framework to index and compare LCA courses.

# Research Methodology

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## Qualification of Syllabi

16 syllabi were collected from different sources to develop a comparative assessment and database. The syllabi were collected through web searches (where instructors posted their syllabi publicly) and through email contacts with instructors, and represent courses in a number of disciplines. Note that the syllabi likely represent only a small fraction of the total active LCA courses across the U.S.. Courses that did not primarily focus on LCA (e.g., Industrial Ecology classes that had short LCA modules) were excluded. Figure 1 shows an overview of these universities. Note that two universities (University of California, Berkeley, and University of California, Los Angeles) each have two LCA courses.



*Figure 1: Institutions where LCA syllabi were collected*

## Syllabi Indexing

Due to terminology across syllabi, a classification method was used to compare commensurate information. This is further referred to as Broad Classification Components. Five Broad Classification Components were used to aggregate the course topics as shown in Table 1.

*Table 1: Broad Classification Components used to classify and aggregate course topics taught in LCA courses, Specific examples for each broad category and the corresponding color used for each category in the database*

<b>Broad Classification Components</b>	<b>Specific Examples</b>	<b>Database Color coding</b>
Framework and components of LCA	Goal and Scope Definition, Functional Unit, Reference Flows, System Boundary Selection, Inventory Analysis, Impact Assessment	Green
Types of LCA	Process LCA, Hybrid LCA, Social LCA	Grey
Auxiliary analysis of LCA	Weighting, Life Cycle Costing, Sensitivity and Uncertainty	Yellow
Applications of LCA	Case studies, Focused LCAs	Pink
Software and Tools	SimaPro, OpenLCA, GaBi	Blue

Additional categories related to assessment and teaching tools (i.e. homework, quiz, test, project, or in class activity) were also identified.

### **Time Allocation Analysis**

A time allocation analysis was performed to determine the fraction of time spent in each course related to each Broad Classification Component. The unit time used for the analysis was an average class period of 75 minutes. Using the dates/weeks mentioned in the syllabi along with topics, the number of unit hours spent teaching a given topic was estimated. The counts for each Broad Classification Component were then presented as a proportion of the total time spent teaching all course topics. Subsequently, the average time and other descriptive statistics were calculated for proportions of time allocated in a course to teach each Broad Classification Component.

## **Results and Discussion**

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While LCA courses are taught across the U.S., publicly accessible syllabi in combination with those emailed to the authors were collected from the universities shown in Figure 1. The syllabi were predominantly collected from universities in the Northeast and Southwest, with a few in the Midwest (Figure 1). Again, syllabi were collected based on publicly available posting of content and personal relationships, and should not be assumed to be spatially representative.

### **Description of Course Instructors**

A summary of course instructors is shown in Table 2. These results indicate that LCA courses are predominately taught by faculty with a background and a position title in engineering or environmental sciences. The only exception to this is one public health faculty.

Table 2: Overview of Course Instructors

<b>Name</b>	<b>Position</b>	<b>School</b>	<b>Background</b>
Alice M. Agogino	Professor of Mechanical Engineering	UC Berkeley	BS, MS - Mechanical Engineering, PhD - Engineering Economics
Arpad Horvath	Professor of Civil and Environmental Engineering	UC Berkeley	BS, MS, PhD - Civil Engineering
Christine Costello	Assistant Professor of Industrial & Manufacturing Systems Engineering	University of Missouri	BS, MS, PhD - Environmental Engineering
Christopher J. Meinrenken	Associate Research Scientist of Earth and Environmental Engineering	Columbia University	PhD - Physics
Deepak Rajagopal	Assistant Professor of the Institute of the Environment and Sustainability	UC Los Angeles	B.Tech, MS - Mechanical Engineering, PhD - Energy Resources
Eric Masanet	Associate Professor of Mechanical Engineering, Chemical and Biological Engineering	Northwestern University	BS, MS, PhD - Mechanical Engineering
Fu Zhao	Associate Professor of Mechanical Engineering and EEE	Purdue University	PS, ME, MS, PhD - Mechanical Engineering
Gregory Norris	Adjunct Lecturer of Harvard T. H. Chan School of Public Health	Harvard University	Education Not Published (PhD from New Hampshire)
Gwen DiPietro	Part Time Instructor of Civil and Environmental Engineering	Carnegie Mellon	BS - Chemical Engineering, MS, PhD - Civil and Environmental Engineering
Jason Hill	Associate Professor of Bioproducts and Biosystems Engineering	University of Minnesota	A.B - Biology, PhD Plant Biological Sciences
Joyce Cooper	Adjunct Professor of Civil and Environmental Engineering	University of Washington	BS - Mechanical Engineering, MS, PhD - Civil and Environmental Engineering
Mikhail Chester	Associate Professor of Civil, Environmental, and Sustainable Engineering	Arizona State University	BS, MS, PhD - Civil & Environmental Engineering, BS - Public Policy
Richard A Venditti	Professor of Forest Biomaterials	North Carolina State University	PhD- Chemical Engineering, B.S. - Paper Science and Engineering
Roland Geyer	Associate Professor of Environmental Science and Management	UC Santa Barbara	MS - Physics, PhD - Engineering
Vikas Khanna	Associate Professor of Civil and Environmental Engineering	University of Pittsburgh	BE, MS, PhD - Chemical Engineering, MS - Applied Statistics

## Analysis of LCA Course Departments

LCA is taught across a wide range of disciplines. Of the 16 syllabi collected, 9 different departments were identified that teach LCA. LCA is most widely taught in Engineering departments, with 7 syllabi of the presented in the dataset. These syllabi were from Civil, Environmental and Sustainable Engineering (4), and Mechanical Engineering (3). Two syllabi came from Environmental Studies and Earth and Environmental Sciences departments, and one each from Environmental Science, Forest Biomaterials, Bio-products and Biosystems Engineering, and Industrial and Manufacturing Systems Engineering. This indicates that predominately engineering or environmental departments are focused on LCA.

*Table 3: Departments where LCA courses are offered*

Departments	Number of Syllabi
Environmental Science	1
Civil and Environmental Engineering , and Sustainable Engineering	4
Environmental Studies	2
Mechanical Engineering	3
Forest Biomaterials	1
Paper Science and Engineering	1
Bioproducts and Biosystems Engineering	1
Earth and Environmental Sciences	2
Industrial and Manufacturing Systems Engineering	1

## Graduate vs. Undergraduate

Of the 16 syllabi collected, 10 courses were offered only at the undergraduate level, 2 were offered at both the undergraduate and graduate level, and 4 were offered only at the graduate level. The courses were determined either to be undergraduate or graduate courses via the course number, and subsequent verification using academic course catalog available on each school's website. In comparison, in a total of 21 U.S. LCA courses, Cooper and Fava (2000) found 9 courses offered at the undergraduate level, 11 at the graduate level, and 8 as both graduate and undergraduate. Our sample size is low so it is possible that our representation of graduate and undergraduate courses is not representative.

## Use of Software

Of the 16 courses examined, 8 courses had content focused on LCA software and tools. The most common software used to either conduct homework assignments or presented throughout the course was SimaPro, with 3 of the 16 having teaching centered on SimaPro. The second most common software application was Sustainable Minds. Two courses used other software and tools (GaBi and OpenLCA) through integrated assignments and homework. The course that focuses on GaBi (University of California, Santa Barbara) integrates the software into lab sessions throughout the semester which students are supposed to use for their end of semester projects. TRACI and

GREET were identified as additional LCA tools, but were only covered in one class each. There were also 4 courses that did not appear to cover software tools.

## Teaching Material

While there are a number of recommended textbooks in learning Life Cycle Assessment across the syllabi evaluated, *Life Cycle Assessment: Quantitative Approaches for Decisions that Matter* by Matthews, Hendrickson, and Matthews, was the most common, used in 6 of the courses. Courses that used one book used either *The Computational Structure of Life Cycle Assessment* by Heijungs, *Environmental Life Cycle Assessment* by Jolliet, *Life Cycle Assessment Handbook* by Curran, *Handbook on Life Cycle Assessment* by Guinee, *Environmental Life Cycle Assessment* by White (developed by the American Center for Life Cycle Assessment), or *The Hitchhiker's Guide to LCA* by Baumann Tillman. The open access availability of Matthews may explain why it is being aggressively adopted.

## Time Allocation Analysis

The time spent teaching each Broad Classification Component as a proportion of the total time is shown in Figure 2. On average, the majority of time (36.8%) was spent on Frameworks and Components including Goal and Scope Definition, Functional Unit, Reference Flows, System Boundary Selection, Inventory Analysis, and Impact Assessment (Table 1). This is not surprising since this content is foundational for all courses. The second largest percentage of time was allocated to Applications of LCA (23.6%) which included case studies on previous LCAs under specific topics (e.g., construction, energy, transportation), or LCA applications at the broader scale (i.e., corporate and social). Following was Auxiliary Analysis (17.3%) including Weighting, Life Cycle Costing, Sensitivity and Uncertainty, and then Types of LCA (13.0%) including process-based, economic input-output, hybrid, and social. Software and Tools had the least time spent on average (9.2%), however, it is likely that the use of software and tools took place outside of lecture in projects and homework assignments.

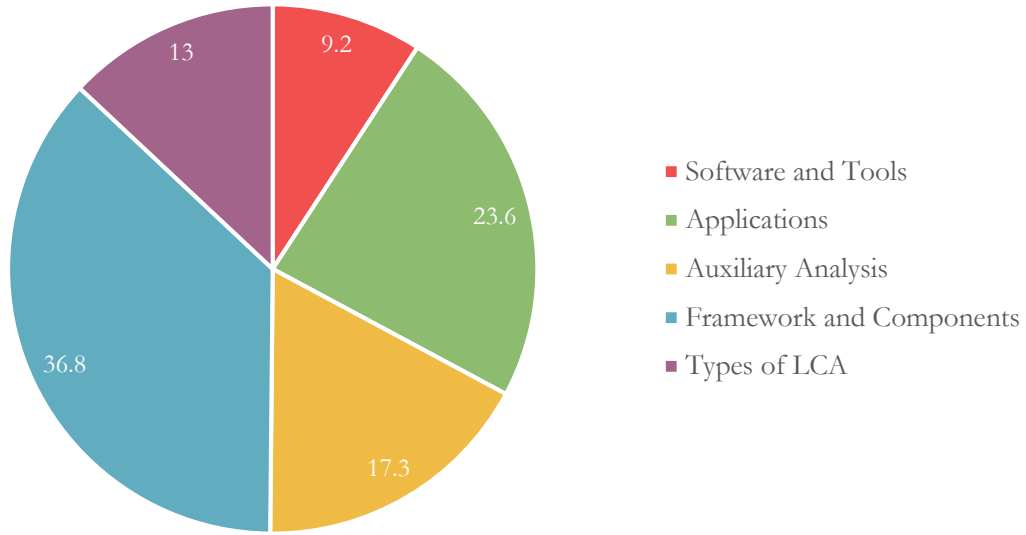


Figure 2: Percentage of time spent on each Broad Classification Component

The data collected across the 16 universities showed significant similarities in themes. All of the course syllabi reviewed the Goal and Scope Definition, Functional Unit, Reference Flows, System Boundary Selection, Inventory Analysis, and Impact Assessment concepts. North Carolina State University spent the most amount of time on what was defined as “Framework and Components.”

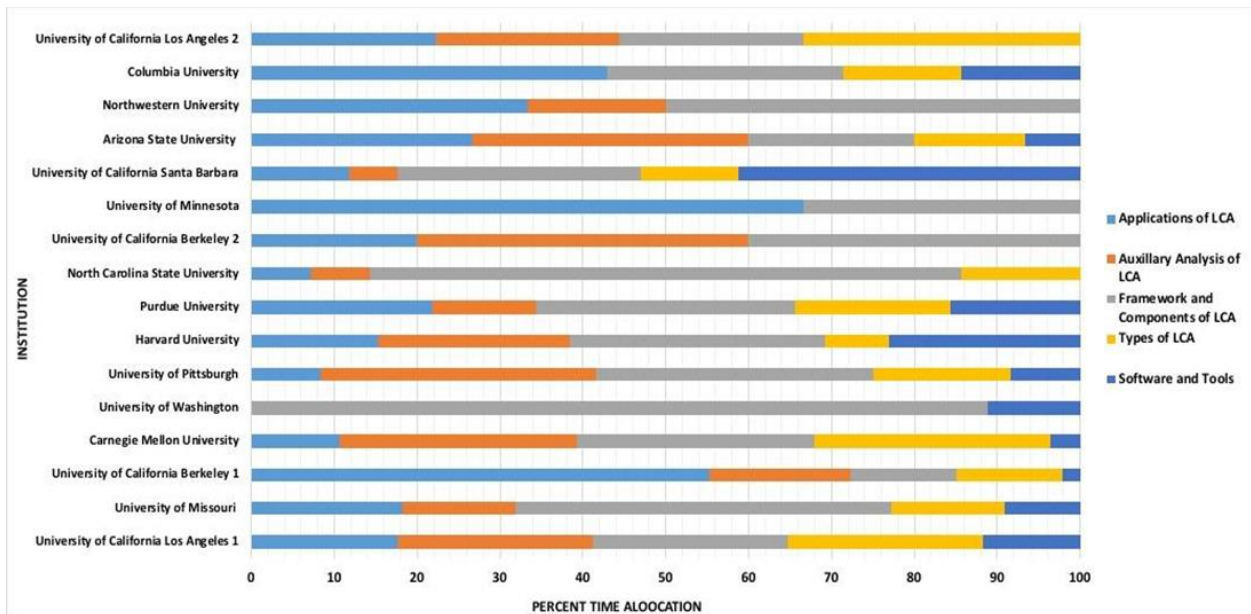


Figure 3: Time allocation for each Broad Classification Component

For each course, the time spent teaching each Broad Classification Component as a proportion of the total time was estimated (Figure 4). Among the 16 courses, 8 courses devoted the highest

proportion of the course time to teach Frameworks and Components of LCA. For three of the courses, Applications of LCA had the highest time allotment. Software and Tools was taught in 11 of the 16 courses, but had the lowest time allotment for the majority of these cases. Courses that offer the highest percent allotment for each Broad Classification Component were identified (Table 4). It is likely that these professors have particular expertise in the component.

*Table 4: Highest percent time allocation teaching each Broad Classification Component*

<b>Broad Classification Components</b>	<b>Course with the Highest Time Allocation</b>
Framework and components of LCA	Life Cycle Assessment (UW) <i>Joyce Cooper</i>
Types of LCA	Tools for Environmental Sustainability Assessment (UCLA) <i>Deepak Rajagopal</i>
Auxiliary analysis of LCA	Life Cycle Thinking in Engineering Design (UC Berkeley) <i>Dr. Agogino</i>
Applications of LCA	Environmental Life Cycle Analysis (UM) <i>Jason Hill</i>
Software and Tools	Life Cycle Assessment (GaBi) (UC Santa Barbara) <i>Roland Geyer</i>

The courses were different in terms of their focus. For instance, the LCA course at Purdue University and the University of California, Santa Barbara devoted a greater proportion of time to teaching software through lab sessions. Dr. Zhao from Purdue University and Dr. Horvath from University of California Berkeley spent considerable time on case studies across various sectors. There were also LCA courses taught with specific objectives, such as the one credit class from University of California, Berkeley that has a focus on Life Cycle Thinking in Engineering Design.

### **Case Studies**

To teach and provide more in depth content to broad topic categories, it was found that 5 courses emphasized the use of case studies. The remaining 11 courses relied more on textbooks, supplemental reading, and lecture content. All courses at a minimum covered content relating to applications of LCA, and some used specific case studies to comprehensively review previously conducted LCAs for different fields.

## Teaching Methods

The most common form of assessment was to have students participate in a semester long applied project followed by a final report. This structure seems to allow instructors to incrementally go deeper into content that is required on the final report as students' understanding on the subject matter progresses throughout the semester. More than 50% of the courses used homework regularly to assess students. This ranged from a 2-3 homeworks through the semester to bi-weekly homeworks. Use of quizzes was rather uncommon, and only two courses used this means of assessment.

## Database Overview

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Each syllabi was indexed in an Excel spreadsheet with the following information: name of the professor teaching the course, contact email address, university, title of the course, department at where the course is taught, main textbook used, homework and assignments associated with the course, link to the syllabus, and main topics covered. The spreadsheet database can be augmented, and should serve as an exploration and possibly foundation for more exhaustive studies.

## Limitations and Assumptions

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We were limited to the publicly available syllabi made available through institution websites and those willing to share them. Access restrictions to many LCA syllabi across the country limited the available number for the review. Direct contact with the faculty teaching these courses could help overcome this barrier and increase the sample size of the analysis and database.

The diversity in terminology used to discuss similar topics among different syllabi required interpretation. We often had to make educated guesses about content given general descriptions of lectures or assignments. This led us to use Broad Classification Components for comparisons. This aggregation leads to the loss of detailed exploration of topics.

The analysis on time allotment for each Broad Classification Component, and all subsequent inferences and comparisons are based on the assumption of average class times.

Assignment and homework were often listed in the format "Homework 1, 2, x" corresponding to a particular class day, along with a due date. Without additional information regarding the content covered in these assignments it was assumed that the homework covered content from recent lectures.

## Conclusion and Future Work

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We identified and categorized 16 LCA course syllabi from universities across the U.S.. An augmentation of this work to other universities in the U.S. and abroad could provide invaluable information to lecturers and students, and lead to content sharing, for both instructors and students. As the LCA framework develops, it can be expected that the number of LCA courses increases. As this happens, new instructors will be tasked with creating new courses, and having access to a robust database may reduce workload but more importantly begin to provide standards and assessments of best practices to the benefit of students.

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