Sustainable Transportation Curricula

March 2015

A Report from the National Center for Sustainable Transportation

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EXECUTIVE SUMMARY

Transportation systems play a central role in a sustainable society by providing mobility for people, goods, and services. Significant sustainability benefits are being derived via improvements in transportation network efficiency, sales and use of high-efficiency vehicles, substitution of alternative fuels, use of alternative modes and multimodality, integration of sustainable design, better integration of land use and transportation systems, etc.. A major goal of the National Center for Sustainable Transportation (NCST) is to ensure that current and future transportation professionals are equipped with the necessary knowledge and skills to design, operate, and maintain sustainable transportation systems.

Over the last decade, the education community has placed an increased emphasis on the incorporation of sustainability principles into academic programs. Much of this effort has been occurring at the grass-roots level, with sustainability modules appearing in individual courses or implemented through new sustainability programs at various universities. However, structured frameworks are generally preferred in the development of new education initiatives (Murphy et al., 2009). The goal of this report is to provide a structured review of existing sustainable transportation courses to serve as foundation for the development of NCST model curriculum, and to support similar curriculum and course development initiatives elsewhere. This report provides an inventory of transportation-related courses and course concepts developed through a review of the literature, existing course syllabi, textbooks, and reference books. The report also surveys models and modeling support tools, current research topics, and industry job descriptions to identify room for growth in sustainable transportation curricula.

The review of the literature reinforces the concept that sustainable transportation is interdisciplinary in nature

Key Findings

- A majority of transportation-related courses with a sustainability focus offered at the six NCST partner universities are environmentally-oriented
- With respect to the sustainability triple-bottom line, more focus could be applied to economic and social sustainability
- Few models and support tools to aid in assessing and meeting transportation sustainability goals are currently being used as teaching tools
- Job announcements appear to be more focused on policy and modeling, which differs from the current environmental focus of courses
- New curricula should strengthen the emphasis on resource economics, systems analysis, modeling, and social sciences
- Employing modeling tools in teaching may help promote an integrative approach that enables students to think holistically about sustainability throughout the entire transportation system lifecycle

(consistent with the holistic basis of sustainability), thereby providing unique opportunities for educators to incorporate sustainable principles into existing academic courses. The team identified academic engineering, planning, and policy courses with a sustainability focus from the course offerings of the six NCST partner universities. An analysis of the topics and structures of these existing courses indicated that a majority of these courses are environmentally-oriented and offered under the discipline of Civil and Environmental Engineering. The research team identified textbooks and reference books that might provide a more complete overview of sustainable transportation and help guide students toward the "triple bottom line" definition of sustainability that incorporates economic, environmental, and social aspects. Models and support tools to aid in assessing and meeting goals related to transportation sustainability were also identified and evaluated as potential support tools for use in sustainable transportation education. Very few of these models are currently being used as teaching tools, and integrating them into transportation sustainability courses could significantly benefit education programs. A review of other transportation sustainability teaching and research programs helped to establish the current state of sustainable transportation curricula within academia. The team reviewed the academic and professional literature to identify current topics of research interest in sustainable transportation education. Finally, the team reviewed posted career opportunities to identify what elements of sustainability are being requested of graduates in the job market, finding that the focus of research and industry may be different than provided in courses that are currently offered. Based on the comparison between educational initiatives in academia and job postings at outside agencies, research appears to have a greater focus on planning and industry appears to have a greater focus on regulations and software proficiency.

Concluding remarks discuss common themes in existing curricula, including the general environmental focus and the diversity of delivery methods, identify unique aspects of certain programs, highlight potential course content shortfalls, and recommend the inclusion of specific sustainable transportation topics in sustainable transportation courses. A series of forthcoming open-source courses developed by NCST partner universities will emphasize practical ways to analyze transportation systems and assess their impacts on transportation accessibility, economic performance, the environment, and quality of life. Instructors at any university will be able to use the five-week course modules in an a la carte fashion to strengthen the sustainability elements of their own courses, or to develop new courses. The modular structure will provide both breadth and depth in sustainable transportation topics. The goal of the sustainable transportation education project is to develop materials that will produce graduates (and train practitioners) capable of using and improving the analytical tools for assessing sustainable transportation systems.

1. Introduction

Transportation plays a major role in sustainability, in terms of resource consumption, environmental impacts, economic impacts, and social impacts. Over the last 35 years, transportation-related expenditures have consistently accounted for somewhere between 10% and 17% of Gross Domestic Product in the United States (USDOT, 2014a; USDOT, 2014b; Winston, 2013) and likely exceeded all expenditures on health care. The transportation sector also provides about 14% of US jobs (USDOT, 2014b). The construction, operation, and maintenance of transportation infrastructure systems, and the associated derived transportation demand, have a tremendous impact on energy consumption and the environment. The transportation sector is heavily dependent on petroleum, which meets more than 96% of transportation demand (USDOT, 2013b). Since 1960, transportation has been responsible for about 65% of daily US petroleum consumption, and the share has increased over the last eight years to about 70% per year (USDOT, 2013a). Transportation has contributed at least 30% of total U.S. carbon dioxide emissions since 1990 (about 39% in 2009) and transportation's share is now larger than the industrial sector (USDOT, 2013b). Given the importance of transportation to the economy, the vulnerability of energy supplies, and the impacts of transportation activity, top federal and state policy priorities now include transitioning to higher efficiency vehicles and alternative fuels, improving the efficiency of transportation networks (including the use of alternative modes and multimodal options), and integrating land use in transportation decision making.

The transportation system figures prominently in the urban systems framework (Figure 1). Transportation infrastructure impacts include: land use consumption for each urban transportation mode network (airports, freeways, arterials, rail lines, bike lanes, sidewalks, etc.), direct and indirect impacts arising from vehicle use, impacts from operation and maintenance of each mode (lifecycle costs), and even the impacts associated with the fuel distribution infrastructure (petroleum pipelines, terminals, and gas stations, electricity transmission and charging stations, natural gas distribution systems for natural gas, biofuels, hydrogen, etc.). Secondary impacts on energy consumption, water use, natural resources, construction materials demand, labor and capital inputs, and emissions are noteworthy and need to be quantified for use in policy analysis. Unfortunately, the direct effects and complex interactions associated with transportation infrastructure decisions are not well understood or modeled during transportation planning and policy processes.

Every year, state departments of transportation collectively make transportation planning and construction decisions that allocate billions of dollars and establish the transportation system that Americans will be living with for generations. Decisions regarding whether cities should continue to expand freeways, implement managed lanes, develop new transit systems, design around automated vehicles, or shift toward electric or natural-gas vehicles all require proper tools and training if planners and engineers are to assess the true economic costs and lifecycle energy and emissions impacts of these technologies. To this end, sustainable transportation education programs need to highlight the complex interactions illustrated in Figure 1.

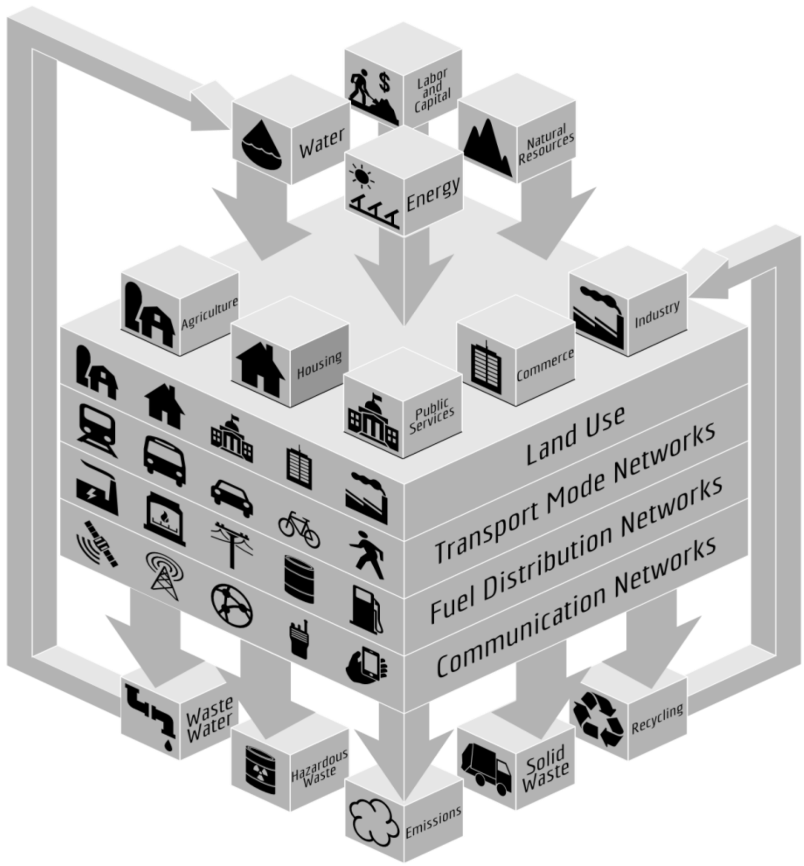

Figure 1. Urban System Framework (Guensler, 2014)

Development and implementation of rational transportation policies require that policymakers, and the technical experts that support policymakers, understand the complex interactive nature of urban infrastructure systems. A major goal of research and teaching universities operating in this field is to ensure that sustainable transportation curricula are available to meet the needs of future policymakers. This report summarizes the findings of a 2014 review of sustainability curricula in transportation education programs that was conducted by the National Center for Sustainable Transportation (NCST). The purpose of this review is to inform the development and enrichment of sustainable transportation curricula across the country.

The nationwide review of relevant course materials presented in this report identified topics covered in existing courses, evaluated pedagogies, and reviewed textbooks and reference books employed in teaching and research. The course review results indicate that current sustainable transportation courses focus more on the environmental component of sustainability than they do on economics and social issues. The most common course pedagogy employed is the standard professorial lecture, with students completing readings before attending class. As a result, students write reports and essays related to readings and typically deliver an end of term project to demonstrate their level of comprehension. Among the textbooks and reference books reviewed, most begin with a similar introduction to the problems of non-sustainable transportation and address themes such as the consequences of auto-centric design and possible multi-modal solutions. The authors also identified and assessed various analytical frameworks that are, or could be, included in a sustainable transportation curriculum. A review of other transportation sustainability teaching and research programs helped to establish the current state of sustainability transportation curricula within academia. In addition to reviewing academic materials, the team assessed job advertisements and position descriptions of state departments of transportation related to sustainability to help identify the skill sets that are expected of transportation planners and engineers. The results indicate that industry is currently focused on the environmental aspect of sustainability, but that industry also appears to place a significant emphasis on policy, planning, and the use analytical tools.

This report is also designed to help the NCST partner universities develop a series of eight, modular, sustainable transportation courses, spread across undergraduate, graduate, and professional education levels (Georgia Tech CEE, 2014). The new courses will focus on teaching practical ways to analyze transportation systems and assess the potential impacts of these systems on fuel consumption and the environment. The goal is to help current and future transportation decision-makers better understand the cause-effect relationships affecting transportation plans and programs. The content of course modules will evolve over time, based upon stakeholder input. Once the undergraduate and graduate materials are fully-developed, the modules will be made available, at no cost, to any university to incorporate into their undergraduate and graduate programs. At least two courses over the next two years will also be offered to transportation professionals through the Georgia Tech Professional Education program (Georgia Tech CEE, 2014) and California State University Long Beach. The modular NCST courses are being designed to provide a framework that can be used by other universities in developing their own curricula. The review of existing courses presented in this report, and the development of the modular courses by NCST partners, is intended to inform the growth of the field.

Chapter 2 of this report first provides an overview of "sustainable transportation," as derived from the literature. Chapter 3 summarizes existing sustainable transportation and related courses offered across the nation, derived from previous literature review summaries and an assessment of the syllabi for related courses currently offered by NCST universities. The course content and pedagogies for these courses are summarized in tabular and graphic formats. Chapter 3 also summarizes courses offered in other university programs. Chapter 4 reviews and summarizes the content of recent sustainable transportation textbooks and reference books. In Chapter 5, the research team identified and reviewed existing modeling tools and analytical frameworks that are useful for assessing the environmental, economic, and social impacts of transportation systems. The report presents the modeling tool review in a graphic format that allows readers to see each model's area of applicability (environment, economic, social), by primary transportation activity, and by intended audience. The team searched the Transportation Research International Database (TRID) and identified 470 articles on sustainable transportation education, across 38 journals, and used word clouds in Chapter 6 to illustrate the topics covered. Similarly, Chapter 7 presents the assessed needs of the transportation professional community through a review of job postings and program descriptions in the area of sustainable transportation. The findings indicate that there is an opportunity to offer new courses, or enhance existing courses, that provide a greater emphasis on the application of practical analytical tools that support transportation planning and policy development. Based upon the reviews conducted by the research team, Chapter 8 summarizes the topics that should be considered for incorporation into a series of sustainable transportation courses. As noted above, these topics would also receive an increased focus on practical modeling applications where applicable. Chapter 9 provides the final conclusions and recommendations.

2. Sustainable Transportation

This review begins with a brief discussion on how sustainability concepts can be integrated into transportation curricula. The discussion first reviews the general topic of education for sustainable development (ESD), and then links ESD and the transportation system.

2.1 Education for Sustainable Development

The most consistently cited definition of sustainable development can be found in the "Brundtland Commission" report to the United Nations (World Commission on Environment and Development, 1987):

> *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

Although the term "sustainability" is sometimes seen as being synonymous with "environmentalism," the Brundtland definition's central point is much more broadly defined in terms of 'needs.' In essence, a prosperous and healthy human society ought to be able to continue into the future. Some also argue that sustaining the current quality of life into the foreseeable future is the goal of sustainability. For example, the American Society of Civil Engineers' definition of sustainability specifically identifies "quality of life" as the factor to sustain, without degrading the continued availability of resources (ASCE, 2014):

> *"A set of environmental, economic and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality or availability of natural, economic, and social resources."*

The ASCE definition highlights the "three pillars," or "triple bottom line," adopted by the United Nations General Assembly (2005), which focuses on environmental sustainability, economic sustainability, and social sustainability. Incorporating the "triple bottom line" definition of sustainability in higher education can be challenging (Lozano et al., 2014), given that university curricula are often organized into specialized areas and disciplines (Cortese, 2003, Costanza, 1991, Orr, 1992, and van Weenen, 2000). However, transportation systems encompass all three of these pillars, with significant interactions between natural resources, economics, and social systems. The interdisciplinary nature of transportation presents unique opportunities regarding incorporating sustainability concepts into a university curriculum.

2.2 Subdividing the Transportation System

Transportation systems implementation can be subdivided into three development stages: transportation planning and policy, engineering construction and design, and lifecycle operations of the system. All three of these activities impact environmental, economic, and social sustainability:

Transportation Planning and Policy: The act of monitoring and predicting current and future performance of the transportation system and developing strategies to address potential deficiencies. Such activities include development of transportation plans, programs, and policies, project prioritization, community engagement, management of revenue and expenditures, etc.

Transportation Design and Construction: Engineering and construction activities associated with development of the transportation infrastructure. Design and construction activities flow from planning and policy activities.

Transportation Operations, Maintenance, and End-of-Life Activities: Techniques used to keep transportation infrastructure safe and usable over its operating life. Such activities include servicing, reconstructing, reusing, recycling, and ultimately dismantling and disposing of transportation infrastructure.

Because the vast majority of transportation system elements undergo a lifecycle consisting of all three stages, there is an opportunity to holistically integrate the three pillars of sustainability throughout these stages. Consider pavements: 1) planning activities have predicted that climate change may affect the durability of pavements as a function of temperature, rainfall, geographic location, etc.; 2) engineers are now designing and constructing pavements that will be more resilient to future climate conditions; and 3) future actions by proper authorities need to ensure that future pavements are properly maintained, rehabilitated, and recycled when further repair is no longer practicable. Given the complex relationships between design, construction, and lifecycle operations of transportation systems, it seems logical that education activities should also cut across these three stages, with each stage embodying environmental, economic, and social sustainability. Hence, existing education plans and programs are evaluated in two dimensions with the three pillars of sustainability in one dimension and the three stages of transportation system elements in the other.

3. Existing Courses and Programs in Sustainable Transportation

Universities appear to be increasingly interested in demonstrating that their own institutional operations are sustainable. This interest is evident in the popular use of the STARS rating system (http://stars.ashe.org), and by the number of universities that showcase LEED-certified buildings on their campuses (Georgia Tech OES, 2014; UC Davis, 2014a). Similarly, universities appear increasingly interested in demonstrating that graduates are adequately educated to serve as future leaders in sustainability. For example, curriculum assessment tools are now available to score the content of courses in a program or university (Watson, 2013). This chapter presents an overview of previous reviews of transportation sustainability education. The report then identifies courses offered within the National Center for Sustainable Transportation partner institutions that cover sustainability topics in a transportation context. The report later expands this assessment to other university programs. The results of these assessments are used to identify common content and practice as well as potential shortfalls in sustainable transportation education programming.

3.1 Existing Course Reviews

With the increasing interest in sustainability education, the number of sustainability-related courses and programs has grown over time. A systematic course review can inform educators with regard to the current trends and room for improvement in higher education for sustainability. For example:

- Allen, et al. (2008), performed a comprehensive review of sustainability courses in the United States, with a scope that included all disciplines of engineering. The authors surveyed the administrative heads of 1,368 engineering departments at 364 U.S. universities, about the extent to which sustainability was a focus within their departments; this focus could include offering sustainability courses, redesigning existing courses to reflect understanding of sustainability, or conducting research in sustainability. One finding of the report was that the courses tended to address narrow applications of sustainability (product design), rather than exploring interconnected systems including their social and cultural dimensions. The most common sustainability-focused courses were in energy and power distribution courses. The authors argued that engineering accreditation organizations should "think critically about what should or should not be included in a curriculum into which sustainable engineering has been incorporated." In a related article, Murphy et al. (2009) further noted the "grass-roots" activity in incorporating sustainability in engineering education at U.S. universities, and called for "a set of community standards for sustainable engineering."
- Bhattacharjee, et al. (2011), reviewed sustainability in construction engineering and found a lack of consensus regarding learning objectives and course mechanics for the delivery of sustainability concepts. The authors searched the 128 member universities of the Associated Schools of Construction (ASC) and found that one third of the universities offer one or more courses in sustainable construction at the undergraduate level. The systematic review compared courses offered by class level, prerequisite subjects, and course content. The paper categorized the sustainable construction

course topics into eight groups: 1) environment/ eco-system, 2) health, 3) sustainable construction, 4) sustainable rating systems, 5) role of stakeholders, 6) lifecycle cost, 7) ethics, and 8) community. The course contents in sustainable construction can lend some insights into what can be offered in a sustainable transportation curriculum.

- Wu, et al. (2014) used the database of authors in the 2012 Transportation Research Board annual meeting to identify colleges, schools, and departments at universities in North America and Europe engaged in transportation research. The authors recorded the academic curriculum at each school or department and identified courses that would likely teach sustainable transportation by comparing the course titles and descriptions to a list of terms the authors compiled (the complete list is given in their paper). Out of 4,084 courses in all programs, the authors identified 925 predominantly graduate transportation planning or safety courses at 119 universities that introduced sustainability topics. One finding of the authors is that while U.S. universities tended to offer these courses as electives or graduate-level courses, Canadian and European universities offered them to undergraduates or made them compulsory. Wu, et al. (2014) also noted that the emphasis of environmental sustainability far outweighs the emphasis of economic and social sustainability.

In addition to systematic course reviews, numerous papers have reported efforts to develop individual sustainability courses or programs in engineering disciplines. Civil engineering has been a particularly popular field with respect to incorporating sustainability into the curriculum. Amekudzi and Meyer (2004) reported on the development of a course, Civil Engineering Systems, to introduce systems and sustainability concepts in the undergraduate Civil & Environmental Engineering curriculum at the Georgia Institute of Technology (Georgia Tech). Chau (2007) reported using "a team-based design project with a problem-based learning approach" to integrate sustainability concepts into an undergraduate-level civil engineering curriculum in Hong Kong. Wang (2009) discussed class topics to be included to emphasize sustainability in a Building Construction course. Watson, et al. (2013), assessed the sustainability content of the Civil and Environmental Engineering curriculum at Georgia Tech and found that the courses focused mainly on environmental issues. Lozano and Lozano (2014) presented the recent development of a brand new degree in Engineering for Sustainable Development at Tecnológico de Monterrey, Mexico, and used STAUNCH® (Sustainability Tool for Assessing Universities' Curriculum Holistically) to help the faculty team understand the courses' coverage of sustainable development as well as the faculty's contribution to the university's total offerings in sustainability education.

Review of these background materials helps set the stage for development of a model curriculum in sustainable transportation by the National Center for Sustainable Transportation (Georgia Tech CEE, 2014; UC Davis, 2014a). The literature suggests that in developed economies the focus has been on the environmental element of sustainability. Hence, an in-depth exploration of economic and social sustainability and identification of existing teaching tools is important. The next step in the evaluation process was to identify and review the current courses taught by the NCST partner universities.

3.2 Presumed Base Knowledge

For the purposes of this report, the research team has assumed that students in a sustainable transportation education program have already completed (or are taking concurrently) fundamental transportation courses necessary to understand the basic planning, design, and operations of transportation systems. Baseline knowledge would include materials from courses such as systems engineering, computer programming, probability and statistics, transportation planning, traffic engineering, and/or general transportation systems design. Such courses are often required to receive a B.S. in Civil Engineering (transportation focus) and are usually required for a M.S. in Transportation Engineering. For example, the dual degree M.S. program at Georgia Tech is a two-year program in which students concurrently receive a M.S. in City and Regional Planning and an M.S. in Civil Engineering. The Georgia Tech dual degree program is open to non-engineers; but, students still must complete pre-requisite undergraduate courses in traffic engineering and statistics, and take graduate level courses in transportation statistics, transportation planning, traffic engineering, and engineering research.

A mastery of basic environmental engineering concepts (water, air, soil, etc.), advanced chemistry, organic chemistry, environmental impact assessment, and resource economics is valuable as base knowledge for environmental engineering, and therefore for sustainable transportation. However, these courses are not generally required for transportation degrees. Identifying the topics that should be covered in core undergraduate courses, and what topics should be included in the eight-course sustainable transportation series, is a bit of a challenge because another NCST objective is to make sure that the program is accessible to non-engineers as well as engineers.

As a starting point, the research team reviewed the syllabi of courses with sustainable transportation content currently offered by NCST university partners. Table 1 depicts the level of knowledge currently required in both transportation and other subjects according to the syllabi. Proficiency in basic environmental engineering, economics, and mathematics are necessary for those courses focused on the respective subject. These topics and closely related topics will therefore not be recommended later in this report for integration into a sustainable transportation program, because the topics are assumed to already have already been addressed.

Table 1. Desired Baseline Areas of Proficiency based upon Syllabi Review

Subject	Desired Level of Proficiency
Transportation	➢ Transportation planning ➢ Traffic engineering ➢ Roadway design
Environmental Science	➢ Systems engineering ➢ Environmental systems ➢ Advanced chemistry ➢ Organic chemistry ➢ Air quality ➢ Environmental regulation and policy
Mathematics	➢ Probability and statistics ➢ Linear algebra ➢ Calculus
Economics	➢ Basic principles of microeconomics and macroeconomics ➢ Intermediate microeconomics and macroeconomics ➢ Econometrics (statistical modeling)

Because the NCST aims to make its education program accessible to non-engineers, it is important to assess the knowledge coverage and proficiency level of transportation planning students. Handy et al. (2002) analyzed the curricula from 66 U.S. transportation planning programs and 62 non-planning transportation-related programs. The authors noted a lack of standardization to transportation planning education. In a more recent effort to develop a list of topics already being taught in transportation planning courses, a Nationwide Survey of Transportation Planning Courses (NSTPC) was conducted from November 2004 through April 2005 (Zhou and Soot, 2006). The survey had three major goals: 1) identify and compile a standardized and comprehensive list of topics based on reviews of the latest federal transportation planning legislation and mandates; 2) provide data on topics being taught and where they are being taught across the country; and 3) investigate where graduate transportation education may fall short. This survey was distributed to faculty members in universities across the U.S. Based upon the responses received from 32 different universities (290 universities were surveyed), Zhou and Schweitzer (2009) found that the following topics are being taught in over 50% of the transportation planning courses across the U.S. (Table 2):

Table 2. Transportation Planning Course Topics and Coverage (Zhou & Schweitzer, 2009)

Topics	Coverage Rates (%)
Transportation and land use connections	96%
Travel demand forecasting	96%
Metropolitan planning procedures and processes	89%
Environmental and sustainability issues	85%
Transportation project evaluation and assessment	85%
Public involvement	81%
Environmental impacts of transportation	81%
Multimodal integration	78%
Intelligent transportation systems	78%
Transit planning and management	74%
Software applications in transportation	59%
Pedestrian and bicycle planning	59%
Safety and Planning	52%

Most transportation planning courses appear to cover environmental and sustainability issues (85%) and environmental impacts of transportation (81%). This suggests that current transportation students may have a good understanding of basic environmental aspects of sustainability. Topics such as travel demand forecasting, transportation project evaluation and assessment, and transit planning and management are also covered. Public involvement reflects the social aspect of transportation, but public involvement is a very broad topic that can refer to stakeholders, voter support of transportation policies, or even equity. The list of topics identified earlier in in Table 2 emphasizes the need to further develop the economic and social aspects of sustainability in transportation education.

3.3 A Review of NCST Partner University Courses

The authors compiled an initial list of courses currently offered within the National Center for Sustainable Transportation (NCST) partnership via web searches and interviews with NCST consortium members: University of California, Davis (UC Davis); Georgia Institute of Technology (GT); University of California, Riverside (UCR); University of Vermont (UVM); University of Southern California (USC); and California State University, Long Beach (CSULB). The intent of the inventory was to go beyond course titles and overviews. The team reviewed course syllabi and interviewed program directors and professors offering the courses.

The courses of interest are not necessarily those that transportation students are required to take. Most required courses appear to be fairly broad-based, in which student learns a little about everything, rather than focusing on a particular topic or issue. Elective courses are often more focused on a single topic area.

The courses identified and discussed in this section are typically specialized courses with a more narrow focus than the planning courses discussed in the previous section. Interviews with NCST program directors focused on identifying the academic and professional courses available in their programs, any special certifications offered, and on the definition and purpose of sustainability in a transportation context. Note that the interviews did not necessarily identify all relevant courses at each institution. Figure 2 displays the courses of interest from the NCST universities and their subject matter. The figure is organized horizontally using the three pillars of sustainability, and organized vertically by the three transportation activity categories introduced earlier. For example, ARE275 (*Resource and Environmental Economics)* at UC Davis covers the economic valuation of natural resources; this valuation would be primarily used in long-range planning activities and cost/benefit analyses (operations, maintenance, and end-of-life), and is primarily influenced by concerns about habitat or natural resource preservation (environmental sustainability) and responsible economic growth (economic sustainability).

One finding of the review is that existing courses focus primarily on planning and the identification of transportation problems (i.e., the focus is on planning activities). Much less attention appears to be given to sustainability concerns in the design and construction of transportation facilities and operations, maintenance, and end-of-life. Some of these elements are likely addressed in lectures or seminars but were not specifically included in the syllabi reviewed. Given that transportation graduates often end up involved in design and construction of transportation facilities, and operations, maintenance, and end-of-life decisions in practice, the relative scarcity of courses in these areas represents an opportunity for innovative course development.

The courses identified in Figure 2 are each discussed in more detail in the sections that follow (organized and presented by NCST partner university).

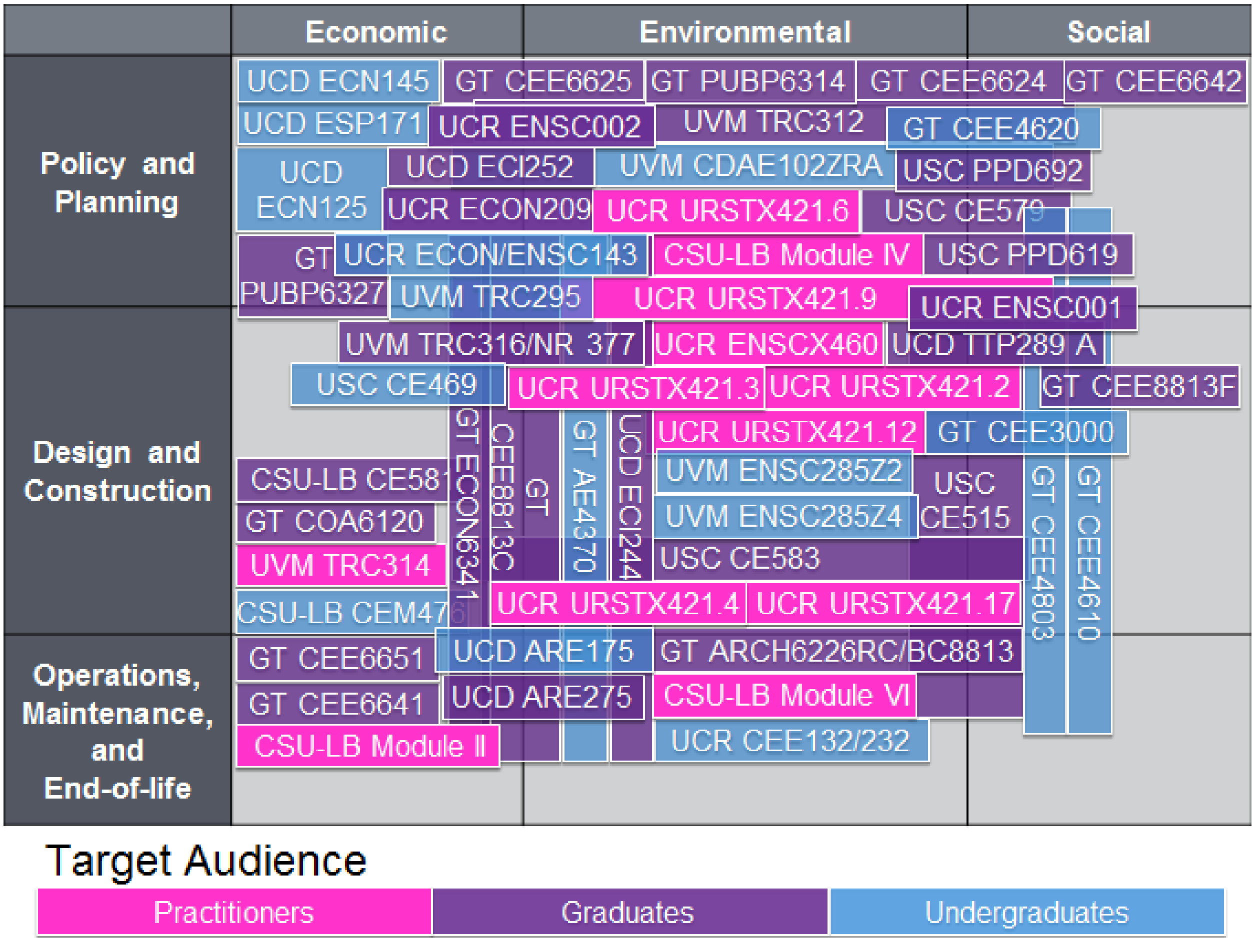

Figure 2. Existing Transportation Sustainability Courses Offered by NCST Members

University of California, Davis (UC Davis)

One of the major strengths of the education programs at UC Davis lies in the integration of natural resource systems and environmental analysis into course materials. These foci, in addition to a general sustainability framework, are emphasized throughout the curriculum. In addition to degrees in Transportation Engineering, UC Davis offers a unique interdisciplinary graduate program, Transportation Technology and Policy (TTP), that emphasizes environmental sustainability. This program offers special topics courses each year in response to emerging issues and student interests. Examples of UC Davis courses with explicit sustainability materials include:

ARE175 Natural Resource Economics - Course topics: economic valuation of natural resources, including land, water, fisheries, and natural habitats; tragedy of the commons; management and regulation of natural resources; regulation and management of resource use and extraction; use of dynamic models for decision making.

ARE275 Resource and Environmental Economics - Course topics: resource allocation models, including dynamic optimization; market failures leading to pollution and degradation; market and non-market corrective policies; policies for addressing global climate change.

ECI252 Sustainable Transportation - Course topics: mobility, accessibility, and origins of auto-centric transportation systems; vehicle efficiency and technology; transportation fuels; investments that limit auto-centrism; policy instruments, markets, and organizations relating to environmental and technology issues; Global Warming Solutions Act of 2006 (California state law). The course employs in-class debates between student groups to address the design and desirability of policies.

ECI244 Lifecycle Assessment for Sustainable Engineering - Course topics: industrial ecology; complete lifecycle design; methods for lifecycle analysis (LCA) and lifecycle cost analysis (LCCA); infrastructure LCA/LCCA; energy system LCA.

ECN125 Efficiency in Energy Markets - Course topics: social surplus associated with energy production and use; policy and energy costs; Pigouvian taxes, cap-and-trade schemes, and command-and-control regulation; California electricity crisis and economic models for decision making.

ECN145 Transportation Economics – Course topics: advanced economics; fundamental problems of planning and financing transportation infrastructure; economics of automobile industry; government regulation, and deregulation in the airline and trucking industries.

ESP171 Urban and Regional Planning - Course topics: city planning processes; developmental styles; plans and zoning codes; environmental impact assessment; data for planning including Census products; environmentally-sensitive growth management. The course focuses on local planning practices and legislation in California, but utilizes examples from other cities in the U.S. to acquire a basic understanding of local and regional planning with respect to law, policy, and practice.

TTP289A Energy Modeling for Policy Analysis - Course topics: energy and fuel supply and demand; energy production technologies; technological change and diffusion; Kaya equation; emissions; scenario modeling; analysis incorporating systemic uncertainty.

Georgia Institute of Technology (Georgia Tech)

The strengths of the Georgia Tech programs are in transportation systems analysis and modeling. The Institute has successfully integrated sustainability throughout the undergraduate and graduate curricula (Watson et al., 2013). A number of specific courses address sustainability concepts directly:

AE4370 Lifecycle Cost Analysis - Course topics: modeling of total cost of complex systems over their entire lifecycle; modeling risk uncertainty for complex energy, environmental, and military systems.

ARCH6226/BC8813 Green Construction – Course topics: LEED; means, method and strategies and technologies to improve energy efficiency and performance of buildings;

reduce environmental impact; building design; material selection; construction process; building operation.

CEE3000 Civil Engineering Systems (Meyer & Jacobs, 2000) - Course topics: sustainability-oriented planning, design, implementation, operations, and renewal of civil engineering systems; professional ethics; quantitative and qualitative system evaluation in environmental, economic, and social terms; uncertainty and sensitivity analysis of systems; technical research and communication.

CEE4610 Multimodal Transport – Course topics: planning, design and operation of systems of air, rail, water and highway facilities (including those for bicycles and pedestrians); defining complete streets; design for pedestrians, bicycles, transit and ADA; urban street design and multimodal performance measurements.

CEE4620 Environmental Impact Assessment - Course topics: environmental legal and regulatory frameworks; sunshine laws; Section 4(f); NEPA goals and objectives; environmental impact assessment processes; project implementation; transportation and air quality conformity; vehicle emission rate modeling; microscale dispersion modeling; noise impact assessment; water quality and wetlands regulation; endangered species; historic preservation; socioeconomic impact assessment; and environmental justice.

CEE4803 Boulevard of Broken Sidewalks (Undergraduate Honors) - Course topics: sidewalks as transportation infrastructure; impacts on urban life; sidewalk usage and accessibility; importance of sidewalks within the context of planning, engineering, and public policy; assessing sidewalk conditions, etc. The course uses lectures, reading discussions, and weekly field research.

CEE6624 Land Use and Transportation - Course topics: decentralization theory; history of urban growth in North America; planning policies for spatial and behavioral changes in cities, including environmental and social costs of decentralization; links between land use, energy consumption, and air pollution; integrated land use and transportation forecasting models; applied analysis of transportation and land use data.

CEE6625 Transportation, Energy and Air Quality - Course topics: energy supply and demand (mode, fuel, etc.); energy and environment as a complex system; engine and vehicle technologies; fuel consumption; emissions and pollution; transportation fuels (petroleum, GNG, LNG, coal, biofuels, and fuel cells); future technologies; transportation demand management; policy alternatives analysis. A major element of this course is well-to-wheel scenario analysis using GREET and MOVES/NONROAD. Student groups compare two alternative scenarios, such as: LNG vs. low sulfur diesel for short sea shipping in 2020. This course was recently split into two three-unit courses: Transportation Energy and Transportation Air Quality.

CEE6641 Transport Infrastructure - Course topics: traffic control and safety; issues addressed in initial implementation of transportation facilities as well as daily operational aspects.

CEE6642 Transit System Planning & Design – Course topics: benefits and challenges of different transit modes; data for measuring transit performance; ridership analysis; quality of service with respect to changes in ITS and right-of-way; station design and location; long-term benefit-cost analysis; future of transit technologies.

CEE6651 Infrastructure Systems – Course topics: asset management, principles, methodologies, models and tools to assist efficient infrastructure investments (transportation is the main case study); review of infrastructure status; infrastructure needs assessment approaches; condition assessment methods; performance prediction models; project evaluation methods; project prioritization methods; asset valuation methods; policy and regulation affecting infrastructure/asset management.

CEE8813C Sustainable Engineering - Course topics: interactions between the human and natural environment; resource consumption; environmental pollution; earth systems and management; environmental, economic, and social issues; lifecycle analysis; urban metabolism; industrial ecology; business modeling; quantitative tools to assess impacts; design for sustainability.

CEE8813F Complete Streets Design – Course topics: focus on the need, purpose and design for multimodality; defining complete streets and focuses on the five E's of cycling and walking (engineering, education, encouragement, enforcement, evaluation and planning).

COA6120 Retrofitting Suburbia – Course topics: retrofitting of dead malls, dying office parks, decaying subdivisions, decaying commercial strip corridors; re-inhabiting redeveloping and re-greening; advancing sustainable urban design at the building neighborhood and metropolitan scale.

ECON6341 Transportation Economics – Course topics: economic and finance aspect of transportation, and resource allocation issues; transportation investment decisions; complexity of public transportation investment; combine principles of economics, management, engineering, and social politics.

PUBP6314 Policy Tools for Managing the Environment - Course topics: regulations, managerial and legal mechanism available to policy analyst and decision makers for protecting environmental quality.

PUBP6327 Sustainable and Environmental Policy - Course topics: analyzing alternative disciplinary definitions and approaches by incorporating economic, ethical, and political approaches to sustainability, and by introducing a broadly procedural approach to identifying and pursuing sustainability goals.

University of Vermont (UVM)

The courses at UVM are very focused on climate change, climate change response and adaptation, and land use planning and economics. UVM offers a graduate certificate in sustainable transportation. This certificate is offered to graduate students in planning and civil engineering, and also to professionals who aspire for advancement in leadership and policy positions. Students pursuing the Sustainable Transportation Systems and Planning certificate must complete three courses:

TRC312 Critical Issues in Transportation - Course topics: transportation and economic development; policy effects on environment, energy, culture, equity, and quality-of-life; integrated and cooperative solutions. The course is built around seminars including guest speakers that present background and proposed solutions to these issues.

TRC314 Travel Safety and Human Factors - Course topics: safety concerns in human factors and behavior, performance, environment, and road design; safety measurement and reporting; statistical analysis of crash data; common countermeasures for traffic safety improvement; transportation safety for non-highway modes. A major element of course design is the completion of position papers.

TRC316/NR377 Land Use Policy and Economics - Course topics: urban economics; urban decentralization; zoning and land use controls; transportation and energy; growth management; urban density and infill; regionalism; farmland and open space preservation.

None of these courses exclusively focus on sustainability; rather, the courses teach important concepts and methods in transportation from a sustainability perspective. Of particular interest to sustainability programs is UVM's Transportation System Institute, created by the university's Transportation Research Center (TRC) to help and support the growth and development of current employees and attract new talent to the Vermont Department of Transportation through mentoring, succession planning, and continuing education. The TRC also offers classes to the general student body including the following bioenergy course. UVM has integrated a sustainability emphasis in their Community Development and Applied Economics (CDAE) and Environmental Science (ENSC) programs as illustrated in the courses below:

CDAE102ZRA Sustainable Communities Development- Course topics: introduction to perspectives and methods used to develop healthy communities that are economically, socially, and environmentally sustainable using rural and urban, U.S. and international examples.

ENSC285 Z2 Green Building- Course topics: theory and practice of how green buildings are designed and built; energy, water and materials used in buildings; energy efficiency; resource-smart; green building standards; passive solar design; indoor air quality; climate control; rain water harvest; green roofs; environmentally friendly landscaping.

ENSC285 Z4 Solutions: Using Science and Systems to Design Sustainable Outcomes- Course topics: problem assessment, systems thinking, design and implementation of solution, green design of the built environment; renewable energy; energy efficiency; sustainable ecology; green infrastructure; ecosystem management; group dynamics.

TRC295 Bioenergy: Biomass to Biofuels- Course topics: wood biomass energy; fuel wood possible reduction of greenhouse gas emissions; grass energy; biodiesel; oilseed crops suitable for New England production; integrated sustainability assessments of biofuels; economics of biofuels; transportation and biofuels.

University of California Riverside (UCR)

UCR has made sustainability education a major institutional focus; this is manifest in university-wide policies on waste management, transportation systems, and other areas. The university has also consolidated information on courses with a sustainability focus on a dedicated webpage (http://sustainability.ucr.edu/programs/academics.html). Given the broad and interdisciplinary nature of sustainability, these courses all address one or more of the following areas: environmental science, management, environmental quality, natural resource use, wildlife ecology or management, political science, and environmental policy. The following courses contain coursework or discussions relevant to transportation:

CEE132/CEE232 Green Engineering - Course topics: environmental risk assessment; environmental regulations; chemical pollution prevention; product lifecycle assessment; industrial ecology.

ECON209 Non-market Valuation and Environmental Policy - Course topics: environmental demand; utility valuation and discrete choice modeling; hedonic wage and price models; empirical applications.

ECON/ENSC143 Ecological Economics and Environmental Valuation - Course topics: natural resource valuation; environment-economy interactions; damage valuation and pollution control; efficient and equitable economic policy.

ENSC001 Natural Resources - Course topics: ecosystem characteristics and function; population dynamics; impacts of population on environment; energy and resource conservation and management.

ENSC002 Environmental Quality & ECON006 - Course topics: principles of economics; natural resource utilization and scarcity; market failures and environmental degradation; government and policy interventions.

The UCR continuing education office offers a Sustainable Development and Green Building Design professional certificate program. The certification process consists of a series of six required courses that combines elements from architecture, civil engineering, landscape architecture, environmental and land use planning, and construction. The certification program is designed for working professionals moving into related fields. Four of the six courses relate to transportation and are summarized below:

URST X421.2 Sustainable Planning, Environmental Site Design and Development - Course topics: sustainability processes applied to community planning and design; land use planning, smart growth and urban design; transportation policy and design; site assessment and selection; Brownfield redevelopment strategies; and infill development.

URST X421.3 Sustainable Water Resources Management in Site Design and Landscaping - Course topics: assessing long term water use/demand; sustainable landscape design; water quality and wastewater treatment in urban area; and sustainability principles for urban streams and wetland sites.

URST X421.4 Green Architecture - Course topics: issues, challenges and opportunities with green building and sustainable design; innovative residential, commercial, industrial, mixed-use, and low-density and high-density buildings; micro- and macro-economic issues with green building; and thermal, water and lighting control systems.

URST X421.6 Energy Sources, End Uses and Impacts - Course topics: energy use; effectiveness of renewable energy resources; and energy conservation in the built environment.

URST X421.17 Building Efficiencies: Low carbon and Renewable Energy - Course topics: heat flow in buildings; natural and mechanical means of heating, cooling and ventilation to improve indoor air quality and cost savings; energy use; and effectiveness of renewable resources.

UC Riverside's continuing education office also offers a Professional Certificate in Community and Regional Planning that emphasizes the needs of future communities and he challenges planners face as they cope with limited resources and the ever-increasing demand of a growing population. The program focuses on sustainability, technology, urban design and trends, mobility/transit and social equity with three areas of concentration: Mobility Planning, Urban Design, and Environmental and Public Health Planning. The following courses emphasize the sustainability aspects of transportation:

ENSCX460 Sustainable Planning, Design and Development - Course topics: design principles and techniques for sustainable development and sustainable cities; smart growth theory; transportation development; sustainable infrastructure and urbanism.

URST X421.9 Planning for Bicycle, Pedestrians, and Transit - Course topics: practices of alternative travel modes including bicycle, pedestrian and transit; planning for alternative modes.

URST X421.12 Urban Design and Analysis - Course topics: how to design the public realm; importance of streets and street design; understanding codes, zoning, and land use regulations in urban design.

University of Southern California (USC)

The Masters of Science in Civil Engineering (Transportation Systems) is part of the Sustainable Infrastructure Systems program, designed to prepare students for immediate and effective participation in the modern infrastructure workforce. The common core of the program includes smart-system design for sustainable infrastructure, the societal and regulatory context of infrastructure engineering decisions, and construction management. Also, the Sol Price School of Public Policy offers graduate specialization degrees and certificates in sustainably-oriented development that students can obtain while pursuing their main graduate degree in the School of Public Policy: Civil Infrastructure Systems Specialization, Certificate in Sustainable Cities and Certification in Transportation Systems. The following courses can be used to satisfy degree requirements in both the Civil Engineering and the Public Policy graduate programs.

CE469 Sustainable Design and Construction - Course topics: green building practices; sustainability implemented through design and construction industries; sustainable project design; carbon footprints; manufacturing and transportation.

CE515 Sustainable Infrastructure Systems - Course topics: analysis, planning and maintenance of various types of infrastructure, including power systems, water and waste systems, transportation systems, and communication systems.

CE579 Introduction to Transportation Planning Law - Course topics: Federal and California law for construction of transportation-related public works projects.

CE583 Design of Transportation Facilities- Course topics: understanding the process of transportation projects from initiation to completion and the factors that influence the project, such as social, economic, and environmental considerations.

PPD619 Smart Growth and Urban Sprawl: Policy Debates and Planning Solutions - Course topics: analytical models of land use and interaction of land uses with environmental quality and natural resources.

PPD692 Transportation and the Environment - Course topics: Analysis of benefits and costs of urban transportation; concepts of social costs and environmental costs; social justice issues; policy and planning alternatives for sustainable transportation.

California State University, Long Beach (CSULB)

The civil engineering department at California State University, Long Beach has a significant focus on construction management, which provides a unique perspective on sustainability in transportation. The upper-level undergraduate and graduate courses in the civil engineering department provide a sustainable outlook on construction and maintenance of vital transportation projects. The following courses address construction sustainability:

CE581 Sustainability and Green Construction- Course topics: green building design and construction practices through high-performance, market-leading design, construction, and operation practices; green operations and management of new construction and major renovation projects, with emphasis on green building rating systems.

CEM476 Construction and Maintenance of Infrastructure- Course Topics: coverage of the construction principles and technologies embraced by the heavy civil industry; construction methods and maintenance practices of heavy civil projects, with emphasis on utility pipes, bridges and roads.

CSULB also offers a Professional Designation Program for Global Logistics Specialists (GLS). As part of the Center for International Trade and Transportation (CITT), the GLS program consist of five course modules and one capstone module, providing training for professionals involved in the international movement of goods. The program addresses global freight and shipping, the cost of moving goods domestically and internationally, international supply chains, innovations and industry trends, and how to develop, implement, and present integrated logistics plans. In addition to covering the logistical aspect of trade and transportation, the program also emphasizes innovation and current industry trends, including sustainability. The following modules highlight trade sustainability with regard to regulations and transportation:

Module II- Transportation/Logistics Management- Course topics: trucking- links between seaport, rail yards, and airports to the manufacturing plants; understanding the requirements of the US DOT/FMCSA for motor carriers; the history of intermodal transportation and the benefits of relevant alternative shipping methods; services provided by freight forwarders; revenue generation.

Module IV - World Trade & Government Regulatory Bodies - Course topics: U.S. Customs and border protection, informed compliance and paperless processing; trends in world trade and goods movement policy; global alliance; transportation infrastructure and environmental issues; environmental mitigation; greening of the supply chain and reduction in carbon emissions and greenhouse gases; alternative transportation fuels and energy; sustainability planning for greenhouse gasses.

Module VI – Capstone Project – Course topics: students are guided in the development of an integrated logistics plan for a fictitious retailer where the possible strategies used in the development of the plan include those tied to sourcing of raw materials, fleet management, trade lanes and distribution patterns. Students are introduced to sustainable supply chain strategies and to the tools used to estimate emissions reductions and the environmental benefits resulting from the use of alternative fuels, different transportation and distribution patterns, packaging, etc.

CSULB also designs and delivers professional development programs for state and regional agencies. For example, CSULB offers a four-day goods movement and freight seminar twice per year for Caltrans staff that includes materials on sustainable freight transport trends. CITT is also developing a similar course in freight operations for the California Air Resources Board. Topics covered in this course include relevant state regulatory mandates and the economics of freight operations, including the impact of environmental programs on the supply chain. Other topics relevant to sustainability include the implications of changes to land use or commercial behavior on freight movements. CITT also offers professional certificates in port operations and hazardous materials handling that might provide resources to the curriculum.

3.4 Structure of NCST Partner Courses

The syllabi of the NCST partner courses indicate that the majority employ lectures and readings as the primary teaching tools and means of information delivery. Students also typically prepare reports and/or essays based upon readings and research, and deliver some sort of analytical term project. Some courses are based entirely on a single term project. In addition to the standard structure of lectures, exams, and term projects, a few courses require students to attend supplementary sections (e.g., labs and discussions), complete problem sets, facilitate debates in class, and participate in out-of-classroom activities. The following tables (one for each university) display the structure of the relevant classes offered by the NCST universities. The general information includes class number/name, credit hours, and whether the course is taught in a traditional lecture environment, where the professor lectures and students are expected to read relevant material before class. The weighting of various class assignment types toward the class grade is also presented graphically. Courses with many assignments may require the instructor to cover a wider range of topics in class for students to successfully complete each assignment; hence, such courses are more likely to be lecture-based. Courses that have large written assignments and/or semester projects are often more informal and have more student-faculty discussion, because the student must be able to translate the concepts/theory into real-world problem solving methods.

The column labeled “Problem Sets” refers to any homework or critical thinking problems given to students to further assist in understanding the concepts being taught in class. “Semester Project” includes any group or individual project that requires the student to apply the principles learned in class to solve a realistic or real-world problem. “Testing” refers to quizzes, midterms, and/or final exams. “Written Assignments” incorporates literature summaries, formal lab reports, and essays. Lastly, the field labeled “Other” encompasses all the unique or less task oriented components of the course such as class participation, leading discussions, participation in debates or games, assessment of presentation quality, etc.

Table 3. Relevant Courses at the University of California, Davis

Class Number/ Name	Credit Hours	Lecture	Problem Sets	Semester Project	Testing	Written Assignments	Other
ARE175 Natural Resource and Environment Economic	4	Yes	40%	0%	25%	25%	10%
ARE275 Resource and Environment Policies	4	Student-led Presentation	0%	30%	60%	0%	10%
ECI252 Sustainable Transportation	3	Debates	0%	0%	0%	80%	20%
ECI244 Lifecycle Assessment for Sustainable Engineering	3	Yes	0%	25%	15%	35%	25%
ECN125 Efficiency in Energy Markets	4	Yes	20%	0%	60%	0%	20%
ECN145 Transportation Economics	4	Yes	40%	0%	25%	25%	10%
ESP171 Urban and Regional Planning	4	Yes	15%	0%	35%	40%	10%
TTP289A Energy Modeling for Policy Analysis	4	Yes	60%	25%	0%	0%	15%

Table 4. Relevant Courses at the Georgia Institute of Technology

Class Number/ Name	Credit Hours	Lecture	Problem Sets	Semester Project	Testing	Written Assignments	Other
AE4370 Lifecycle Cost Analysis	3	Yes	30%	0%	30%	30%	10%
ARCH6226/BC8813 Green Construction	3	Yes	35%	20%	35%	0%	10%
CEE3000 Civil Engineering Systems	3	Yes	25%	20%	40%	10%	5%
CEE4610 Multimodal Transport	3	Yes	20%	50%	20%	0%	10%
CEE4620 Environmental Impact Assessment	3	Yes	15%	35%	0%	35%	15%
CEE4803 Boulevard of Broken Sidewalks (Honors)	3	Yes	20%	30%	20%	20%	10%
CEE6624 Land Use and Transportation	3	Yes	0%	30%	55%	0%	15%
CEE6625 Transportation, Energy and Air Quality	3	Yes	0%	100%	0%	0%	0%
CEE6641 Transport Infrastructure	3	Yes	20%	30%	20%	20%	10%

Class Number/ Name	Credit Hours	Lecture	Problem Sets	Semester Project	Testing	Written Assignments	Other
CEE6642 Transit System Planning & Design	3	Yes	30%	40%	20%	0%	10%
CEE6651 Infrastructure Systems	3	Yes	30%	0%	30%	35%	5%
CEE8813C Sustainable Engineering	3	Yes	25%	40%	25%	10%	0%
CEE8813F Complete Streets Design	3	Yes	20%	50%	20%	0%	10%
COA6120 Retrofitting Suburbia	3	Yes	0%	50%	0%	25%	25%
ECON6341 Transportation Economics	3	Yes	35%	45%	0%	0%	20%
PUBP6314 Policy Tools for Managing the Environment	3	Yes	20%	35%	0%	35%	10%
PUBP6327 Sustainable and Environmental Policy	3	Yes	0%	40%	35%	0%	25%

Table 5. Relevant Courses at the University of Vermont

Class Number/ Name	Credit Hours	Lecture	Problem Sets	Semester Project	Testing	Written Assignments	Other
TRC312 Critical Issues in Transportation	3	Yes	0%	40%	20%	24%	16%
TRC314 Travel Safety and Human Factors	3	Yes	0%	40%	32%	28%	0%
TRC316/NR377 Land Use Policy and Economics	3	Yes	0%	10%	20%	35%	35%
TRC295 Bioenergy: Biomass to Biofuels	3	Yes	0%	35%	0%	35%	30%
CDAE102 ZRA Sustainable Communities Development	3	Yes	20%	30%	20%	15%	15%
ENSC285 Z2 Green Building	3	Yes	20%	30%	45%	0%	5%
ENSC285 Z4 Solutions: Using Science and Systems to Design Sustainable Outcomes	3	Yes	0%	100%	0%	0%	0%

Table 6. Relevant Courses at the University of California, Riverside

Class Number/ Name	Credit Hours	Lecture	Problem Sets	Semester Project	Testing	Written Assignments	Other
CEE132/232 Green Engineering	3	Yes	0%	35%	15%	35%	15%
ECON209 Non-market Valuation and Environmental Policy	3	Yes	35%	0%	15%	35%	15%
ECON/ENSC143 Ecological Economics and Environmental Valuation	3	Yes	25%	0%	25%	35%	15%
ENSC001 Natural Resources	3	Yes	0%	35%	15%	35%	15%
ENSC002 Environmental Quality	3	Yes	0%	0%	30%	35%	35%
URSTX421.2 Sustainable Planning, Environ. Site Design and Development	2	Yes	0%	100%	0%	0%	0%
URSTX421.3 Sustainable Water Resource Mgt. in Site Design/Landscape	2	Yes	0%	100%	0%	0%	0%
URSTX421.3 Green Architecture	2	Yes	0%	100%	0%	0%	0%

Class Number/ Name	Credit Hours	Lecture	Problem Sets	Semester Project	Testing	Written Assignments	Other
URSTX421.6 Energy Sources, End Use and Impact	2	Yes	0%	100%	0%	0%	0%
URSTX421.12 Urban Design and Analysis	2	Yes	0%	100%	0%	0%	0%
URSTX421.9 Planning for Bicycle, Pedestrian and Transit	2	Yes	0%	100%	0%	0%	0%
ENSC X460 Sustainable Planning Design/Development	2	Yes	0%	100%	0%	0%	0%

Table 7. Relevant Courses at the University of Southern California

Class Number/ Name	Credit Hours	Lecture	Problem Sets	Semester Project	Testing	Written Assignments	Other
CE515 Sustainable Infrastructure Systems	3	Yes	20%	30%	20%	20%	10%
CE469 Sustainable Design and Construction	3	Yes	20%	0%	70%	0%	10%
CE579 Introduction to Transportation Planning Law	3	Yes	50%	0%	35%	0%	15%
CE583 Design of Transportation Facilities	3	Yes	15%	15%	70%	0%	0%
PPD619 Smart-Growth and Urban Sprawl: Policy Debates and Planning Solutions	4	Debates	0%	0%	0%	50%	50%
PPD692 Transportation and the Environment	4	Yes	0%	25%	0%	50%	25%

Table 8. Relevant Courses at the California State University, Long Beach

Class Number/ Name	Credit Hours	Lecture	Problem Sets	Semester Project	Testing	Written Assignments	Other
CE581 Sustainability and Green Construction	3	Yes	0%	50%	25%	25%	0%
CEM476 Construction and Maintenance of Infrastructure Facilities	2	Yes	15%	35%	25%	25%	0%
Module II - Transportation/Logistics Management	N/A	Yes (Online or on campus)	0%	50%	25%	25%	0%
Module IV World Trade & Government Regulatory Bodies	N/A	Yes (Online or on campus)	0%	50%	25%	25%	0%

Problem Sets - Problem sets are not as common in graduate level classes as they are in undergraduate level course, but almost half of the courses use problem sets to keep students accountable for reading and comprehension. In reviewing the 55 courses, 23 (~42%) employ problem sets to reinforce the assigned readings and to help students to gain familiarity with policies or modeling tools. For classes that employ problem sets, the final grade contribution of the problem sets is typically 20% or less, meaning that the student's comprehension is mainly assessed through other means, such as a semester project or written assignments. For those courses in which the problem set portion counts for more than 20%, the subject matter is either focused on quantitative practice, such as model analysis, or policy related, requiring student to understand the practicality of the policy. The following courses place a great deal of grade emphasis on problem sets:

- *ARE175 - Natural Resource Economics (40%)*
- *ECN145- Transportation Economics (40%)*
- *TTP289A - Energy Modeling for Policy Analysis (60%)*
- *AE4370 - Lifecycle Cost Analysis (30%)*
- *ARCH6226/BC8813 - Green Construction (35%)*
- *CEE3000 - Civil Engineering Systems (25%)*
- *CEE6642 - Transit System Planning & Design (30%)*
- *CEE6651- Infrastructure Systems (30%)*
- *CEE8813C - Sustainable Engineering (25%)*
- *ECON6341- Transportation Economics (35%)*
- *ECON209 - Non-market Valuation and Environmental Policy (35%)*
- *ECON/ENSC143 - Ecological Economics and Environmental Valuation (25%)*
- *CE579 - Introduction to Transportation Planning Law (50%)*

Lab Sections - Only one of the 45 courses reviewed requires students to undertake regular laboratory assignments. *CEE6624 Land Use and Transportation* (Georgia Tech) offers students two lab sessions throughout the semester to learn skills needed to create and analyze their own integrated land use and travel behavior dataset.

Discussion Sections - As an alternative to conventional lectures, some classes encourage students to learn and share their opinions on the subject matter through student-led debates and presentations. For example, *ESP171 Urban and Regional Planning* (UC Davis) includes formal discussion sections during which students host course content discussions and lead debates on the topics covered in the course, with the intent to reinforce and develop fluency in the course concepts. Discussion sections in many courses are also used to facilitate structured faculty-student, teaching assistant-student, and student-student meetings, such as reviewing class exercises and exams, peer-editing papers, and holding workshops on the use of census data. Students are required to prepare an engaging discussion or presentation based on required readings and any relevant current events. A successful debate or presentation requires that students critically review required readings, and understand the theme of the reading as well as the important details relevant to the area of study. The following courses include student-led debates and presentations: *ECI252 Sustainable Transportation (UC Davis),* *PPD619 Smart Growth and Urban Sprawl: Policy Debates and Planning Solutions* (USC) and *ARE275 Resource and Environmental Economics* (UC Davis).

Case Study Scenario Analysis - Requiring students to apply their research skills to forecasting the potential impacts of future development scenarios can increase their understanding of the complex interactions of transportation system elements and energy sub-systems. Students can also learn firsthand how difficult it is to forecast future scenarios, given the paucity of current data and our limited understanding of long term changes in travel behavior. For example, *CEE6625 Transportation Energy and Air Quality* (Georgia Tech) requires student teams to compare the implementation of two competing alternative fuel/technology scenarios, for a specific transportation sector, for a given future year. For example, in 2014, one of the student groups assessed hydrogen fuel cell light-duty vehicles vs. plug-in hybrid-electric gasoline vehicles for 2040. Students develop the fleet composition forecasts and apply GREET and other models to predict the net impact on well-to-wheel energy consumption. For 2014/2015, the course was split into a transportation energy course and a transportation air quality course, with scenario analysis conducted in each course. The CSULB Global Logistics Specialist program also uses a case study approach as part of its capstone project.

Gaming and Simulation - Hands-on activities that are challenging and entertaining provide students with an opportunity to better understand complex systems. For example, the "OPEC Games" included in *ECN125 Efficiency in Energy Markets* at UC Davis is a series of simulations of the world oil market developed by Jim Bushnell (UC Davis) and Severin Borenstein (UC Berkeley). Delegations of three-students participate in the game, prepare strategy memos, and prepare an OPEC game debriefing for class.

Field Trips - Facility operations tours, site visits, and other out of classroom activities can support student visualization and understanding of innovations in bioenergy. For example, *TRC295 Bioenergy: Biomass to Biofuels,* offered at UVM, requires student to attend various production operations to gain hands-on experience in the production of wood and grass alcohol fuels, waste vegetable oil-based biodiesel, crop-based (oil seed) biodiesel, algae biofuel, etc. Similarly, individual classes within the CSULB GLS program are taught on site, at locations such as marine terminals. Understanding sub-sectors of the transportation system and how alternative energy sources are used within the community helps the student create projects where implementation of alternative bioenergy or biofuel can be successful and innovative.

3.5 Additional Programs in Sustainable Transportation Education

To supplement the range of different sustainable transportation courses and course topics, a Google search using the keywords "Sustainable Transportation University Education Programs" was conducted. The Google search identified many universities outside of the NCST partners with educational programs in sustainable transportation, or with an accumulation of courses that collectively have a sustainability focus. The rank order of universities in the Google search return provides no indication as to the depth or quality of the university program, nor does the search return necessarily indicate whether the university actually has a "sustainable transportation education program." Many of the higher ranked search returns link to university parking and transportation program websites that include discussions of activities that the university is taking to make their transportation systems more sustainable (i.e., completely unrelated to sustainable transportation coursework). However, the search return did provide a great deal of valuable information regarding additional sustainability topics covered by other universities. The universities identified in the Google search were added to the list of universities identified in the Allen, et al., (2008) and Wu, et al., (2014) papers to create a list of 50 universities with potential sustainable transportation programs or courses.

The potential programs that were identified in the online review included, in alphabetical order: Arizona State University; Boise State University; Boston University; Clarkson University; Colorado State University; Columbia University; George Washington University; Georgetown University; Harvard University; Michigan Technological University; North Carolina State University; Ohio State University; Oxford University; Portland State University; Roosevelt University; San Jose State University; Santa Clara; Seattle University; Stanford University; Syracuse University; Temple University; Texas A&M; SUNY Buffalo; University of Alaska, Fairbanks; University of California, Berkeley; University of California, Santa Cruz; University of Colorado at Boulder; University of District of Columbia; University of Connecticut; University of Florida; University of Idaho; University of Illinois; University of Louisville; University of Massachusetts, Amherst; University of Massachusetts, Lowell; University of Michigan; University of Minnesota; University of New Hampshire; University of New Mexico; University of Oregon; University of Portland; University of Redlands; University of Texas at Austin; University of Utah; University of Washington; University of Wisconsin, Green Bay; University of Wisconsin, Superior; University of Wisconsin, Milwaukee; Western Michigan University; and Western Washington University.

The team searched the websites for universities with sustainable transportation courses of study and/or programs similar to the online master's program in Sustainable Transportation currently available at University of Washington. The Washington program, geared towards practicing professionals, offers one course each semester in: 1) planning and livable communities, including transportation planning design, livable communities design, and transportation choices and technology; 2) environmental issues and impacts, including sustainable transportation systems, climate change and energy, and environmental assessment; and 3) policy development, health, and economics, including health and sustainable transportation, transportation economics, and policy development, finance, and sustainable transportation. Some universities have research centers focused on sustainable transportation, such as at the University of California at Berkeley. The team also identified universities that offer certificate programs in sustainable transportation similar to that of Columbia University, where two certification programs emphasize sustainability: 1) Masters of Sustainability Management, which focuses on conservation science and environmental policy; and 2) Masters in Earth and Resources Engineering, with three sub-group concentrations on water resources and climate risks, sustainable energy, and integrated waste management.

Out of the 50 universities listed above, the 20 most cited universities outside of the NCST partners were: Arizona State University; Columbia University; North Carolina State University;

Ohio State University; Portland State University; Texas A&M; SUNY Buffalo; University of California, Berkeley; University of California, Santa Cruz; University of Colorado at Boulder; University of Idaho; University of Illinois; University of New Hampshire; University of Oregon; University of Texas at Austin; University of Utah; University of Washington; and Western Washington University.

Other notable programs included the University of Colorado Boulder, for its Business Sustainability Management program; the University of Buffalo, for its certificate in Sustainable Transportation and Logistics; and San Jose State University, for its M.S. degree in Transportation Management. These programs provide interdisciplinary perspectives on sustainability by incorporating transportation business elements, including: funding, mode management, logistics, and resource optimization. Programs such as these are usually geared more toward professional development but are open to all students. Similarly, the University of Michigan offers a Sustainable Systems M.S. program that can be added to, or jointly completed with, a variety of masters of engineering degrees including mechanical engineering, chemical engineering, environmental engineering, and civil engineering. A few course titles offered in the Sustainable Systems program include: Systems Thinking for Sustainable Development, Sustainable Energy Systems, Green Development, and Transportation Energy and Climate. The broad range of topics covered by the Sustainable Systems degree complements the engineering discipline of choice. For an international perspective, Portland State University offers a study abroad course entitled Sustainable Transportation in the Netherlands, were students can see the differences in transportation systems between the US and the Netherlands with respect to the engineering principles and policies present in the Manual of Uniform Traffic Control Devices and the Highway Capacity Manual.

The following section analyzes these sustainable transportation university programs based upon the topics of emphasis. Through the process of topic identification, the research team sought to identify gaps in the interpretation of sustainable transportation that may need to be addressed.

3.6 Summary of Topics in Sustainable Transportation Education

A word cloud, created using Wordle™ Software (http://www.wordle.net), counts the number of times each specific word is used in a set of text documents and then graphically displays the resulting histogram. The size of each word in the figure is in proportion to frequency of use; the largest word being the most frequently used word in the document(s). Word font sizes decrease with decreasing use frequency. Derivations of the same word are combined. For example, the words “technology” and “technologies” are counted together under the word “technologies,” and the words “sustainable” and “sustainability” are counted together under the word “sustainability.” Word clouds are based upon word frequency distributions, which may or may not reflect the actual emphasis placed on each topic; nevertheless, the images are useful for looking at differences across such word distributions.

The word cloud in Figure 3 was created from the descriptions of relevant courses offered by the NCST partners (previous tables in Section 3.5). The course descriptions from the NCST partner universities were attained from the respective syllabi, or the university's website (when the syllabus was not available), or from course catalog. The word cloud shows that words "environmental" and "sustainability" are the most commonly used words in these programs and courses, after the base word "transportation." Planning, design, urban policy, and economics, are not too far behind. The results reinforce the observation that environmental sustainability has received the most attention, followed by economic sustainability. The social elements of sustainability are not as identifiable in the word cloud.

Figure 3. Word Cloud based on NCST Partner University Course Topics

Figure 4 was developed from the program descriptions of the other 20 school referenced above. Syllabi and course descriptions were obtained from their respective university websites. The more frequent topics mentioned on the syllabi and course descriptions are similar to those of the NCST Partner Universities, for example: "transportation," "environmental," "sustainability," "policy," and "planning." A few topics that are being covered by non-NCST universities with more frequency are: "community," "natural resources," and "management." A few other topics not covered in the NCST universities' word cloud include "health," "climate change," and "building." Figure 4 displays the frequencies of the topics being taught at the other 20 schools.

Figure 4. Word Cloud based on Course Topics for 20-Universities (Google Search)

Both word clouds suggest that more emphasis could be placed on the interconnectedness between transportation and other natural and engineering systems. For example, the urban infrastructure system framework (Figure 1) covers energy, as well as labor and capital in economics. “Water resources” is referenced, but the impacts of the transportation system on other natural resources may not be a major focus. Nor are the impacts on other infrastructure systems (industry, commerce, public services, housing, agriculture), and on waste streams (air emissions, waste-water, solid waste, hazardous waste, and recycling), prominent in the word cloud.

4. Review of Existing Textbooks and Reference Books

Numerous textbooks, reference books, readers, and technical manuals are available and used in a variety of sustainable transportation courses. Some of these texts are general purpose, and others are targeted to particular aspects of sustainability. The range of presentation formats is also wide, ranging from technical manuals and design guides to collections of essays. Faculty teaching in the areas of planning, policy, and sustainability often struggle with the decision as to whether to use textbooks, or to use readings that may be available online for free. Scott Rutherford, founder of the University of Washington program, notes that "Some instructors appreciate the flexibility of having many different points of view expressed in readings and the use of up-to-date information" (Rutherford, 2015). In the end, such decisions are the purview of the individual instructors.

4.1 General Textbooks

Six recently-published textbooks have the potential to provide a framework for an undergraduate or graduate course. These six books have numerous elements in common, but each is focused on a different area:

Vanek, et al. (2014). *Sustainable Transportation Systems Engineering.* Topics include: transportation within the context of sustainable development; energy security and climate change; a systems approach to sustainable transportation; understanding mode choice and trip purpose behavior; vehicle design; methods to enhance public transportation systems performance; intra-modal and intermodal approaches; alternative energy; the electric grid; etc. This book also provides references for further reading, case studies and exercises at the end of each section that can easily translate into course assignments.

Cox (2013). *Moving People: Sustainable Transportation Development.* Topics include: inadequacy of transportation methods developed in the West; practical methods to analyze the complexity of post-development theory; transportation case studies; the need for profound changes in planning.

Hutton (2012). *Planning Sustainable Transport*. Topics include: understanding transport systems; sustainability and climate change; use of modes in combinations, not as alternatives; analyzing the short, ancillary segments of transport; managing land use and origin and destination pairs; sustainability defined; transport planning.

Tumlin (2012). *Sustainable Transportation Planning: Tools for Creating Vibrant, Healthy, and Resilient Communities.* Topics include: sustainability defined; mobility vs. accessibility; transportation and public health; street design for bicyclists and pedestrians; public transit planning and design; traffic modeling and design; parking policy and design; travel demand management; transportation metrics; sustainability performance measures.

Black (2010). *Sustainable Transportation: Problems and Solutions.* Topics include: sustainability of transportation in climate change, air quality, petroleum reserves, safety, and traffic congestion; pricing solutions to automobile dependence; sustainability through urban form; policies for addressing vehicle dependence, including travel demand management; sustainability education and outreach; technological improvements in vehicles, communication, and transportation systems.

Schiller, et al. (2010). *An Introduction to Sustainable Transportation: Policy, Planning and Implementation.* Topics include: sustainability and non-sustainability; problems resulting from automobile dependence and possible alternatives; multi-modal infrastructure; sustainability of freight and supply chains; transportation economics and investment; public participation in transportation planning processes; considering maintenance and renewal in transportation plans and policies; example case studies.

Each textbook begins with a similar introduction to the sustainability problems associated with our current transportation system, including its environmental, economic, and social dimensions. Each textbook also addresses several common concepts, such as the non-sustainability of auto-centric design and policies, strategies for travel demand management, and multi-modal solutions. The Black (2010) and Schiller, et al. (2010) texts have a great deal of overlap, although Schiller, et al. (2010) addresses economic and social dimensions more explicitly. The Tumlin (2012) and Hutton (2012) texts contains specific detail and guidelines on multimodal infrastructure design that the other texts lack, making them perhaps useful in a traffic engineering or geometric design classes. Schiller, et al. (2010) emphasizes the history of transportation planning as well as public interaction. One helpful element is the anecdotes showing implementation of the concepts in the real-world. The Black (2010) book presents many concepts, and each chapter ends with a set of discussion questions that could be used for homework or in-class discussion. The Black (2010) text stands out as the text that most strongly emphasizes fuels, energy, and air quality issues.

4.2 Other Readings and Focused Texts

Numerous technical and policy books address sustainability issues in transportation and other fields. As transportation is an interdisciplinary field of study, portions of these books, or the ideas presented in them, may be valuable for lecture material, course work, and/or discussion topics. For example, the Booz Allen Hamilton (2014) and Zeitsman, et al. (2011) reports, whose target audience is state departments of transportation, define sustainability principles and discuss how to instill these principles in society and transportation projects. McDonough and Braungart (2010) focus more on lifecycle analysis and how Western development is affecting the world at large, though they pay little attention to freight distribution mechanisms. With respect to environmental issues, Field and Field (2012), Brown (2011), van Bueren et al. (2012), and Wheeler (2008) address environmental economics and the effects that urban planning and design can have on the environment. Munier (2007) summarizes sustainability issues in various disciplines and attempts to develop sustainability metrics and indicators. These texts are often focused in specific areas but provide useful readings that could be adapted into transportation sustainability courses:

Booz Allen Hamilton (2014). *Strategic Issues Facing Transportation Volume 4: Sustainability as an Organizing Principle for Transportation Agencies (NCHRP Report 750).* Topics include: sustainability; key gaps between present day agency functions and their relevance in a future sustainable society setting; how transportation agencies can better support a sustainable society; recommendations on near-term actions; tools and methods needed to support future societal sustainability planning.

Friedman (2014). *Planning Small and Mid-Sized Towns: Designing and Retrofitting for Sustainability*. Topics include: ideas and methods on how small isolated and edge towns can be designed and retooled into sustainable, affordable and adaptable communities; evolution of small towns, mobility and connectivity; neighborhood and sustainable dwelling design; town centers and urban renewal; economic sustainability and wealth generation.

Vallero, D. (2014). *Fundamentals of Air Pollution, Fifth Edition.* Topics include: a systems perspective; international issues relating to air pollution; a strong interdisciplinary approach to the study of air pollution; air pollution chemistry, physics, meteorology, engineering, toxicology, policy, and regulation.

Field and Field (2012). *Environmental Economics*. Topics include: an introduction and overview of environmental economics, including benefit-cost analysis, market efficiency and failures, and environmental policy analysis; air pollutant emissions; reducing greenhouse gasses and ozone; alternative fuels; analysis of marginal abatement cost curves; regulatory mandates, Pigouvian taxes, and emissions trading as possible solutions to air pollution issues.

Khisty, et al. (2012). *Systems Engineering with Economics, Probability and Statistics.* Topics include: systems analysis; systems thinking; sustainability; problem solving and design in engineering and planning; sustainable development; case studies in engineering and planning for sustainability; development of transportation systems that promote sustainable development; sustainable transportation systems.

Parkin, J. (2012). *Cycling and Sustainability*. London: Emerald. Topics include: a global look at cycling as a sustainable transport mode in numerous geographic and cultural contexts; exploring the difficulties experienced in seeking to mainstream cycling.

Troy, A. (2012). *The Very Hungry City: Urban Energy Efficiency and the Economic Fate of Cities*. New Haven CT: Yale University Press. Topics include: the high energy metabolism of cities; behavior, climate, water supply, building quality, transportation, and other factors that contribute to the energy metabolism of a city; challenges cities will face as energy costs inevitably increase.

van Bueren, et al. (2012). *Sustainable Urban Environments: An Ecosystem Approach*. Topics include: a comprehensive collection of essays (primarily Dutch authors) on diverse aspects of sustainability in urban design including ecology, hydrology, livability, and government.

Brown (2011). *World on the Edge.* Topics include: discussions about how modern civilization and economic patterns are dependent on a healthy environment and how non-sustainable practices harm the environment and human society.

Zeitsman, et al. (2011). *A Guidebook for Sustainability Performance Measurement for Transportation Agencies (NCHRP Report 708).* Topics include: comprehensive guide for

departments of transportation on measuring sustainability impacts of projects and policies; implementing sustainability objectives in long-range transportation plans; implementing sustainability targets in transportation programs; selecting a certification program that may aid in sustainability objectives.

Amekudzi, et al. (2011). *Transportation Planning for Sustainability Guidebook.* Prepared for the Federal Highway Administration, US Department of Transportation. Topics include: critical issues in planning for sustainable transportation systems; a review of U.S. and international practices; potential data sources and tools for sustainability planning and analysis, a range of US and international case studies to highlight best practices.

McDonough and Braungart (2010). *Cradle to Cradle*: Topics include: an overview of consumer product production, use and recycling methodologies; an introduction to lifecycle analysis.

Cambridge Systematics (2009). *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emission.* Topics include: projects and policies that might reduce greenhouse gas emissions and lessen the impact of automobiles on the environment; transportation policy scenarios, including the deregulation of land-use policies, investment in public transportation, ride-sharing, and high-occupancy vehicle lanes.

Schafer et al. (2009). *Transportation in a Climate-Constrained World.* Topics include: the increasing scale of transportation and the effects on the environment; assessing greenhouse gas emissions from passenger transportation; travel demand; technologies; alternative fuels; policies that promote sustainable transportation in the future.

Kutz (2008). *Environmentally Conscious Transportation*. Topics include: foundations for implementing methods for reducing environmental impacts; private vehicles and biofuels; practical analytical techniques for enhancing the reliability of vehicle and infrastructure transportation via lifecycle assessment; measuring pollution caused by transportation activities and strategies to limiting the pollution; social cost of motor-vehicle use in the U.S.; how to maximize profits while meeting environmental objectives.

Meyer (2008). *Design Standards for U.S. Transportation Infrastructure Topics: The Implications of Climate Change.* Topics include: climate-induced changes in the environment; changes to engineering design practices; design practice for subsurface conditions, materials specifications, cross-sections, standard dimensions, drainage and erosion, structures, and location engineering; short-term and long-term implications of climate change.

Savonis, et al. (2008). "Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I." Topics include: multimodal transportation infrastructure in the Gulf Coast region between Galveston, Texas and Mobile, Alabama; potential impacts of climate change on Gulf Coast infrastructure; increased costs of transportation construction, maintenance, and operations; extreme precipitation disruptions; sea level rise and road inundation.

Wheeler (2008). *Sustainable Urban Development Reader (Second Edition).* Topics include: a collection of classic essays on urban planning and development; evolution of thought on urban design; impacts of development on the environment.

Munier (2007). *Introduction to Sustainability: Road to a Better Future*. Topics include: a comprehensive overview of sustainability issues in multiple disciplines; developing sustainability metrics and indicators.

Shoup (2005). *High Cost of Free Parking.* Topics include: the potential benefits of eliminating minimum parking requirements; the need for better professional training with respect to parking; parking costs, subsidies, and demand; proposed alternatives to parking requirements.

Hanson, S., and G. Giuliano, eds. (2004). *The Geography of Urban Transportation*. Topics include: passenger and freight dynamics in the metropolis; the urban transportation planning process; public transit; land use; energy; equity; environmental impacts.

Forman et al. (2002). *Road Ecology: Science and Solution*. Topics include: the lack of information on minimizing the ecological effects of roads and vehicles; a discussion of foundations of road ecology; road, vehicle, and transportation planning; vegetation and roadsides; water, sediment, and chemical flows; aquatic ecosystems; wind, noise, and atmospheric effects; road networks and landscape fragmentation.

Gomez-Ibanez, et al. (1999). *Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer*. Topics include: analytical methods used in transportation economics and policy analysis; policy development and analysis; discussion of automobile as the source of transportation difficulties; key issues in urban public transportation such as funding and congestion; the impact of regulation and deregulation on the U.S. airlines, railroads, and trucking industries.

Cervero (1998). *The Transit Metropolis: A Global Inquiry.* Topics include: examples of successful systems; methods and tools needed to create successful systems; resources for transportation planners, urban planners, designers, policymakers, and students of planning and urban design.

Kay (1997). *Asphalt Nation: How the Automobile Took Over America and How We Can Take It Back.* Topics include: the history of the rise of automobile transport; politics and subsidies; the interdisciplinary nature of transportation problems and solutions; the relevance of economics, politics, architecture, and the public.

Kaya and Yokobori, Eds. (1997). *Environment, Energy, and Economy: Strategies for Sustainability.* Topics include: climate change and possible developments to mitigate adverse effects of climate change; economic aspects of environmental issues, including energy markets and carbon taxes; macroeconomic costs of reducing CO_2 emissions; modeling economically efficient abatement of greenhouse gases.

5. Existing Modeling Tools and Analytical Frameworks

Government agencies, private firms, and non-profit interest groups have developed a wide array of tools and analytical frameworks that can be used to help practitioners develop, evaluate, and accomplish transportation sustainability goals. These tools range from voluntary guides designed to improve decision-making (such as the Federal Highway Administration's INVEST framework), to emissions and energy consumption modeling designed to improve technical analyses (such as USEPA's MOVES model or USDOE's GREET model), to certification programs that can be used to award projects or developments a positive sustainability designation (such as the University of Washington's Greenroads program). In addition to providing help and guidance to trained professionals, these tools can be used to help illustrate the application of sustainability principles in the classroom.

Brodie, et al. (2013) compiled a list of existing analytical sustainability ratings frameworks for the purposes of cross-comparison and differentiation. For example, Brodie, et al. (2013) identified which of the numerous modeling tools consider runoff storage and treatment in assessing the sustainability of the project. Similarly, the team identified modeling tools that consider the three major transportation activities (policy and planning, design and construction, and operations, maintenance and end-of-life) in assessing the sustainability of the project. In the review presented in this section, the research team has included the most comprehensive tools (for instance if Tool A contains all of the elements of Tool B, then Tool B is included only if notable for its widespread use). The focus is on tools that are applicable to the planning environment in the United States, which eliminates some tools focused primarily on meeting European Union regulations.

The matrix in Figure 5 shows where each tool fits into the three major transportation activity categories (policy and planning; design and construction; and operations, maintenance, and end-of-life) and its coverage within the domain of three major sustainability objectives (environmental, economic, and social). Figure 5 also includes color coding of each cell to indicate the primary audience of the analytical tool (researchers, technical experts, and the general public). This figure is designed to be compared to the courses matrix in Figure 1. The practical tools developed to implement sustainability presented in Figure 5 appear to cover the three pillars and the sustainability framework scope more thoroughly than do the existing courses presented in Figure 1. Each analytical tool identified in Figure 5 is described in more detail in the sections that follow.

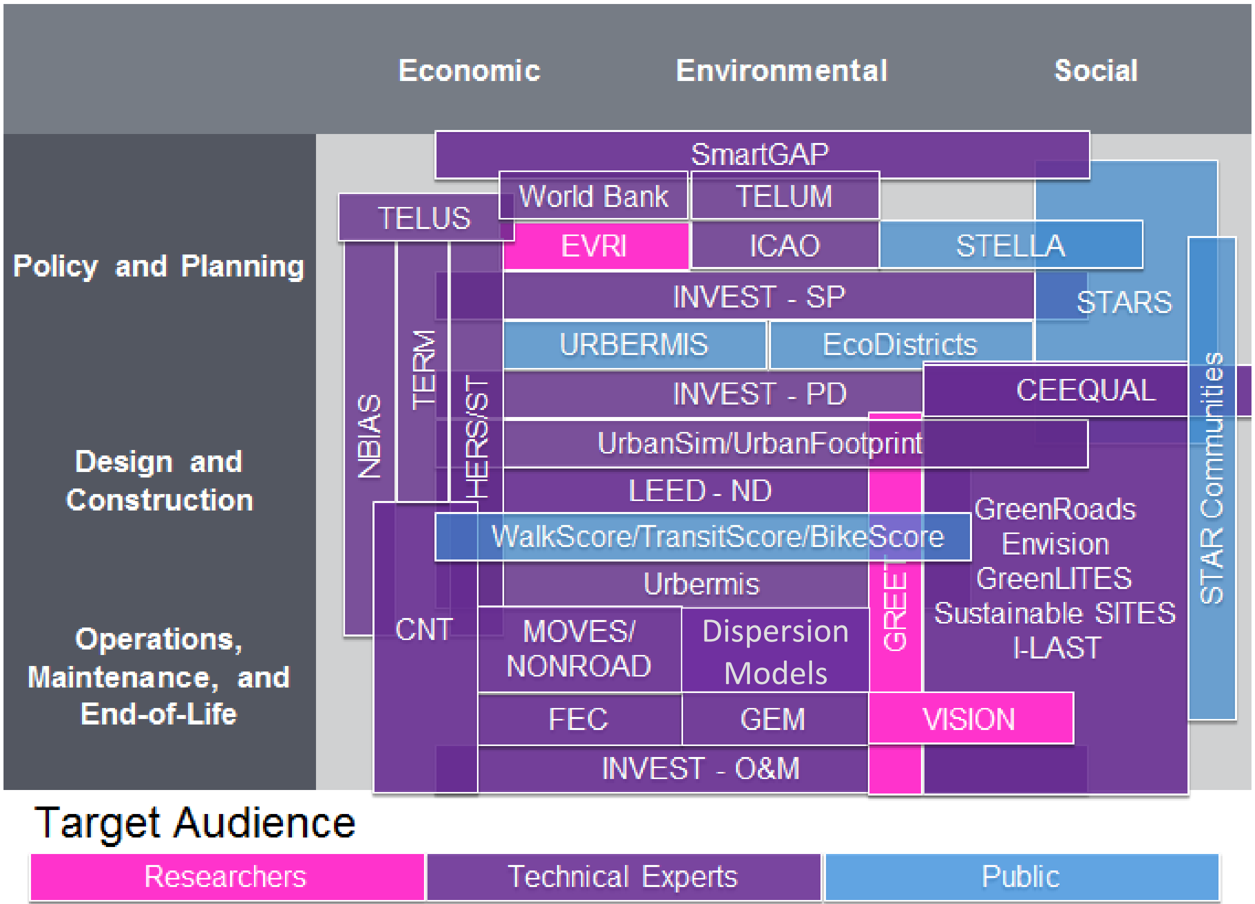

Figure 5. Analytical and Modeling Tools to Implement or Measure Transportation Sustainability

5.1 Models Focused on the Evaluation of Transportation Systems

FHWA Invest

The Federal Highway Administration has developed INVEST as a voluntary tool to assist agencies in implementing sustainability goals in project selection and decision-making frameworks. INVEST is based on topic-focused scorecards grouped into three major areas:

- **System Planning (SP)**: scorecards include factors for integrated planning, safety planning, freight, energy and fuels, and travel demand analysis. Some scorecards also address internal agency policies, such as employee commuting incentives.
- **Project Development (PD)**: scorecards concern the design and construction of transportation facilities. Depending on the facility, different scorecards are available; for instance, "Pedestrian Access" is only applicable to urban projects, whereas "Earthwork Balance" is applicable to projects that expand roadway capacity or rebuild significant structures.

- **Operations and Maintenance (OM)**: scorecards in this area include items such as road weather management, pavement management and maintenance, and traffic control systems.

Each of these three areas is comprehensive enough to be considered its own "tool" in Figure 5. Agencies may use INVEST to assess ongoing agency operations (SP and OM) or to assess individual projects. INVEST awards points for implementing sustainable practices by taking into account social and environmental performance, in addition to economic performance. The goal is not to earn a "level" or a "grade," as in other frameworks. Rather, by scoring itself, an agency may identify changes to promote sustainability that it might not have identified without the framework. Thus, INVEST functions more as a sustainability planning tool, rather than an evaluation tool. Further, many of the SP scorecards (such as those regarding alternative work schedules or commuting modes) can be used by organizations with no connection to the transportation industry.

Greenroads

The Greenroads project was jointly developed by the University of Washington and CH2MHill, and is currently managed by the Greenroads Foundation. The aim of Greenroads is to encourage sustainable roadway construction practices by awarding high grades to thoughtfully-executed projects. Plans are reviewed by Greenroads professionals who advise the project proponent through an initial assessment, document improvement opportunities, and identify supplemental training needed for the project to be awarded a Greenroads designation. After successfully passing the screening process, the proposed project must meet additional requirements such as an environmental review process and a long-term maintenance plan to be awarded a "Greenroads" designation. Points may be obtained for such items as: independent safety audits; runoff flow control; pavement reuse; pedestrian and bicycle access to the roadway, etc. Projects that achieve a "bronze," "silver," or "gold" designation may display a sign on the roadway to advertise the project and a roadways marker to educate the public on the sustainable features of the project.

Greenroads does not consider higher-level planning elements such as the need for the road or site selection. So a highway widening project that might be considered by some groups as non-sustainable in the long term could still qualify for a Greenroads designation (the authors of the tool are aware of this possibility). And although the goal of Greenroads is to build economically and socially sustainable projects, the majority of the credits (72% by their accounting) are aimed explicitly toward environmental goals (but, some of these goals undoubtedly have secondary benefits in the areas economic and social sustainability).

LEED Neighborhood Development (LEED ND)

LEED ND is a rating tool for planned developments, designed to complement other LEED rating systems that are more focused on a single structure. As in other LEED systems, neighborhoods earn a grade based on accomplishing certain goals relating to the design and construction of the structures. In the LEED ND system, a large proportion of the points are given for meeting objectives that are commonly considered sustainable. For example, points are awarded for siting the development at a location where automobile dependence can be reduced, for constructing "walkable" streets, and for designing a high-connectivity street network. As in other LEED systems, projects can be awarded a "platinum," "gold," or "silver" designation based on the number of points earned.

5.2 Emissions and Air Quality Models

Emissions Models: GREET, MOVES, NONROAD, GEM and ICAO

Models designed to predict carbon dioxide and criteria pollutant emissions from infrastructure lifecycle and vehicle operations are important tools in the evaluation of sustainability.

- GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) is an ongoing model development effort by the US Department of Energy's Argonne National Laboratory. GREET is designed to model energy lifecycle outputs in response to proposed changes in transportation and energy policy. For example, GREET can be used to forecast the total lifecycle emissions savings (or costs) that would result from widespread adoption of electric or plug-in-hybrid vehicles into the fleet, explicitly considering the sources of electric power in a region.
- The MOVES (MOtor Vehicle Emissions Simulator) model was developed by the U.S. Environmental Protection Agency (USEPA) to model vehicle emissions. Travel demand model outputs such as traffic volumes and on road congestion levels can be linked with MOVES emission rates to forecasts emissions resulting from future infrastructure development. The MOVES emission rates can also be applied to project impact assessment, for use in preparing environmental impact statements and regional air quality conformity analyses. A related EPA model, NONROAD, forecasts emissions from non-road sources including construction equipment, train engines, aircraft (considering transportation equipment), etc. The EPA has integrated NONROAD into MOVES2014 (USEPA, 2014) to streamline development and expand the possibilities of comparing multi-modal scenarios, such as arise in long-distance passenger travel studies (USEPA, 2012). The California Environmental Protection Agency also employs EMFAC (the California-equivalent of MOVES) which is specifically designed for use with California fleets and regulatory policies.
- The Greenhouse gas Emissions Model (GEM) is a desktop computer application provided by the EPA to estimates the greenhouse gas emissions from heavy-duty vehicles and the effectiveness of certain emissions controls. GEM can be used to estimate the fuel efficiency of specific aspects of heavy-duty vehicles.
- The aviation sector is an important, but sometimes overlooked, source of transportation emissions. Airplane engines and ground support equipment contribute significantly to regional emissions. The International Civil Aviation Organization (ICAO) has developed models and databases that aid planners in studying and forecasting aviation emissions. A full description of these models is beyond the scope of this report, but they are summarized on the ICAO website (ICAO, 2014).

Microscale Dispersion Models: AERMOD, CALINE4, CAL3QHC, R-LINE

Microscale dispersion models are designed to predict near-roadway pollutant concentrations of criterial pollutants such as carbon monoxide (CO), based upon the mass emissions of vehicles on the roadway and the interaction of the resulting plume with atmospheric conditions (wind speed, dispersion parameters, etc.). Dispersion models require input traffic volumes, fleet emission rates (based upon composition data, fuel composition, etc.), and meteorological variables to predict mass emissions from the roadway and how the plume expands and dilutes as it moves downwind. Resulting pollutant concentrations can be employed in health-based studies and in socioeconomic impact assessments.

- AERMOD is a steady state dispersion model designed to address dispersion complexities introduced by complex terrain (USEPA, 2014b). The model includes two input preprocessors (AERMET, a meteorological data pre-processor, and AERMAP, a USGS terrain data preprocessor). The model is typically applied to stationary sources (point, area, and volume sources), but has been adapted and applied to line sources (integration over rectangular volume sources placed above the roadway). The model is complex and not well adapted as a teaching tool within courses (requires extended time and teaching).
- CALINE4 is the simplest microscale dispersion model to operate and provides reasonable worst-case pollutant concentration estimates for highways and major arterials (when operated in the non-intersection modeling mode and paired with applicable MOVES emission rates). The model can be approved by USEPA modeling staff for regulatory analysis, especially for screening analysis of line sources that are not expected to yield exceedances of ambient air quality standards and for comparative scenario analysis. The model is a very useful teaching tool given the transparency of model construction and ease of use. CALINE4 is a useful research tool because the model can be easily batch operated with scripts and all input parameters are relatively simple to generate.
- CAL3QHCR is the current FHWA-recommended line source dispersion model for predicting pollutant concentrations near highways and arterials. CAL3QHCR is based upon the older CALINE3 dispersion parameters, coupled with highway queueing algorithms to estimate corrections associated with delays and queues that occur at signalized intersections. Now that MOVES emission rate improvements have address some of the issues that CAL3QHCR was designed to correct, there is some concern that the model may need to be recalibrated. The model is suitable as a teaching tool.
- R-LINE is a line source dispersion model currently being developed by the US Environmental Protection Agency for predicting near-roadway pollutant concentrations (CMAS, 2014). The research-grade model employs new techniques for generating integrated emissions sources, new vertical and horizontal dispersion coefficients that are based upon more recent wind tunnel and field testing data, and a meander component similar to AERMOD. R-LINE operates with the AERMOD AERMET meteorological pre-processor (with corrections). R-LINE is currently being used in health impact assessment studies. The model has not yet undergone a complete peer

review process, but is likely to be the next approved microscale dispersion model for regulatory analysis.

5.3 Economic Assessment Models

An important aspect of sustainability is developing infrastructure and systems that are affordable to maintain and will aid economic prosperity over the long-term. One limitation to existing cost-benefit analyses can be the failure to appropriately account for the economic costs associated with environmental degradation and/or the full lifetime maintenance costs of the project. However, there are tools available to evaluate these costs.

Evaluating the economic value of environmental assets is a relatively open field. A good introductory guide is a report by the World Bank, *Assessing the Economic Value of Ecosystem Conservation*. This report consolidates much of the research in this area and provides examples of how to approach the valuation problem. Many of the research articles are consolidated in the Environment Canada's *Environmental Valuation Reference Inventory* (http://www.evri.ca), where analysts tasked with evaluating the costs of a project are able to identify relevant studies for their application.

The Center for Neighborhood Technology report entitled *The Value of Green Infrastructure* identifies sustainable development techniques and catalogues their financial benefits in the long term. Most techniques are not related to transportation explicitly, other than installing permeable pavements. The report also provides example calculations demonstrating how the total lifecycle cost of the infrastructure may in some cases be lower than the non-sustainable alternative.

The Highway Economic Requirements System (HERS) is an engineering/economic analysis (EEA) tool designed to evaluate policy options for highway investment. HERS is used by the Federal Highway Administration to develop the Conditions and Performance Report, published every few years, to provide an update to Congress on the condition of the nation's highway system. The FHWA has developed a version of the tool, HERS-ST, for state agency use. HERS-ST is an engineering/economic analysis tool that uses engineering standards to identify highway deficiencies and applies economic criteria to select the most cost-effective mix of highway system improvements.

The National Bridge Investment Analysis System (NBIAS) is used to assess national bridge investment needs. NBIAS is used to model investments in bridge repair, rehabilitation and functional improvements and as a decision support tool to analyze policies to achieve minimum levels of condition and performance for the nation's bridges.

The Transit Economic Requirements Model (TERM) is FTA's capital needs analysis tool. TERM is used to estimate the levels of investment required to achieve various policy objectives, assess the impact of constrained budget on future performance, and conduct benefit-cost analysis of proposed investments. The results are reported in the periodic Conditions and Performance Report to Congress.

5.4 The Transit Fuel and Emissions Calculator (FEC)

The Georgia Tech Transit Fuel and Emissions Calculator (FEC) is a mode-based, lifecycle emissions model and economic analysis tool for transit bus and rail technologies. The FEC compares the fuel consumption, emissions, and economic costs for multiple alternative fuels and powertrains across a range of characteristics and surrounding conditions. The unique mode-based approach allows the model to consider onroad operating conditions (speed/acceleration profiles) and geographic characteristics (road grade) across alternatives. The FEC's modal modeling approach estimates emissions as a function of engine load, which in turn is a function of transit service parameters, including driving cycle (idling and speed-acceleration profile), road grade, and passenger loading. Direct emissions estimates for onroad transit vehicles are derived from the scaled tractive power (STP) operating mode bins and emissions factors employed in U.S. EPA's MOVES (MOtor Vehicle Emissions Simulator) model. Lifecycle emissions estimates are calculated using emissions factors from the GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) model.

The overall objective of the FEC is to facilitate the comparison of emissions performance across different vehicle technologies and across different operating conditions. The model is designed primarily for use by technical policy analysts assessing specific transit technology options for a given set of transit services parameters. Users can select different drivetrain and fuel technologies and then examine the predicted performance of each technology as a function of anticipated on-road operations. For example, transit agencies considering replacement vehicle purchases can assess potential vehicle performance across different transit routes and operating conditions. Model outputs illustrate that the relative greenhouse gas and criteria pollutant emissions for various bus technology-fuel combinations, which are functions of fuel composition, grade, and operating mode characteristics of the transit route. The model also includes a cost-effectiveness module to evaluate the cost per ton of CO_2 reduction across bus technologies.

5.5 Other Modeling Frameworks

There are other sustainability frameworks that transportation professionals should be aware of, and which may be particularly useful for certain types of projects or objectives:

CEEQUAL

CEEQUAL is a rating system developed by a team led by the Institution of Civil Engineers (ICE) in England. This rating system is applied to projects and contracts in the planning stage to assess the infrastructure, landscaping, and public impacts and then rewards those projects that go beyond the legal, environmental, and social minima to achieve an excellent sustainable project. In addition to being a rating system, CEEQUAL promotes sustainable thinking by offering economic models, environmental best practices, and highlight social issues awareness (CEEQUAL, 2013).

EcoDistricts™

EcoDistricts is a non-profit organization that developed the EcoDistricts™ Protocol, which encourages and accelerates the creation of sustainable project development at the district scale. The EcoDistricts™ Protocol focuses on neighborhood size regions and assist with integrate infrastructure and building projects with community action. Four tools are currently being developed to support the framework established by the EcoDistricts™ Protocol: 1) EcoDistrict organization, 2) EcoDistrict Performance and Assessment, 3) EcoDistrict Financing, and 4) EcoDistrict Policy Support. The framework supports and evaluates projects can include bike lanes, green streets, neighborhood energy and water management, public art and smart grid (EcoDistricts, 2013).

GreenLITES

Green Leadership in Transportation and Environmental Sustainability (GreenLITES) was developed by New York State Department of Transportation (NYDOT) to recognize and increase awareness of sustainable methods that NYDOT incorporates into projects. Application of GreenLITES helps expand the use of these methods designed to improve transportation sustainability. The program includes rating systems as well as metrics to assess the projects, plans, operation and maintenance programs, and regional programs (Booz Allen Hamilton, 2014).

I-LAST

Illinois – Livable and Sustainable Transportation (I-LAST) was developed by the Illinois Department of Transportation to provide a comprehensive list of sustainable practices and create a simple way to assess whether a project is sustainable. The goal for sustainable practice, according to I-LAST, is to minimize impact on environmental resources, consumption of material resources, and energy consumption. This tool not only provides a checklist of potential sustainability practices, but provides a list of source material for each practice so that the practitioner can understand and apply the practice (Booz Allen Hamilton, 2014).

ISI Envision

The Institute for Sustainable Infrastructure has developed a rating system that encourages designers of infrastructure projects to reach beyond existing sustainability frameworks and to think of the wider context in which the project is being built. The categories used to assess the project include:

Quality of Life: Located near workforce and/or public transportation, minimal impact.

Leadership: Long-term planning and stakeholder involvement.

Resource Allocation: Minimal use of materials and waste management.

Natural World: Habitat preservation and pollution controls.

Climate and Risk: Greenhouse gas emissions, heat islands.

The framework seems best suited to projects with a defined site, such as a power plant or an intermodal freight terminal. ISI Envision can be seen as a complement and counterpart to Greenroads, which focuses exclusively on roadway infrastructure (ISI, 2014).

PECAS

Created by HBA Specto Incorporated, PECAS is a modeling tool used at the urban and regional level to support transportation and economic planning. PECAS is composed of two principal models: activity allocation and spatial development and works within a spatial economic simulation system (PECAS, 2014).

SmartGAP

This tool is a regional scenario planning tool that estimates the effects of different smart growth strategies on peak-hour travel demand, sprawl, energy reduction, active travel, and carbon footprints. Research and project sponsored by Transportation Research Board for Strategic Highway Research Program on capacity research (Outwater, et al., 2014).

STAR Communities

STAR Communities is a rating system that helps communities identify, validate, and support implementation of best practices to improve sustainable community conditions. The rating system will change to incorporate innovation and changing conditions in the field of community sustainability. With these changes, the rating system will be able to include spatial, temporal, and level of effort details to expand the evidence to advance sustainability conditions for the whole community (STAR Framework, 2014).

STARS

STARS is a rating system developed by the Association for Advancement of Sustainability in Higher Education, whereby colleges and universities can earn credits for teaching sustainability and implementing sustainability concepts into their campus operations. Though the education component is be more limited to academic institutions, the principles related to commuting policies or building operations could be directly adopted by any large campus-type facility, such as a government installation or a large company headquarters (STARS Overview, 2013).

STELLA

The STELLA models allow users to communicate how a system works: system inputs, internal impacts, and outcomes. This model is useful for teaching and potentially bridges the gap between theory and the real-world. Students can easily see the relationships between the system inputs and outputs (STELLA, 2014).

Sustainable SITES

Developed by the U.S. Botanical Garden, Sustainable SITES focuses on landscapes and the ecosystem. Sustainable sites use less energy, water and natural resources, generate less waste, and minimize the impact on land compared to conventional designs (Sustainable SITES Initiative, 2014). A sustainable site is defined as a designed-and-built landscape that is modeled after a healthy ecosystem. In return, the site will increase ecosystem services and benefits to humans produced by the ecosystem over time. The model considers continuous development.

TELUM

TELUM is a software package for evaluating the land use impacts of regional transportation improvement projects. The model is designed to produce long-term forecast of population, employment, and the corresponding needs for land and space in a designated planning area (TELUM, 2014).

TELUS

The purpose of TELUS is to provide user-friendly, comprehensive, and efficient tools for managing Transportation Improvement Programs. TELUS implements web tools to encourage public participation and provide transparency throughout the transportation planning process while meeting the planning and programming requirements of SAFETEA-LU (TELUS, 2014).

UrbanSim/UrbanFootprint

UrbanSim is a simulation system to support planning and analysis of urban development, and incorporates the interactions between land use, transportation, the economy, and the environment. UrbanSim helps explore the impacts of infrastructure and policy choices on community outcomes such as motorized and non-motorized accessibility, housing affordability, and greenhouse gas emissions (Adib, 2014). Similar to UrbanSim, the UrbanFootprint model produces scenario development and ecosystem analysis. UrbanFootprint supports the creation of detailed land use and transport futures and enables scenario-based analysis using various economic, environmental, and public health metrics (Calthorpe Associates, 2014).

Urbemis

This older environmental assessment model estimates daily emissions from land use developments and construction sites (Urbemis, 2007). The model uses California Air Resources Board's EMFAC2007 model for on-road vehicle emissions and OFFROAD2007 for off-road vehicle emissions. The last version, issued in 2008, added PM2.5 and carbon dioxide outputs. Given the age of the model, a technical review is warranted.

VISION

Created by the Argonne National Laboratory, VISION estimates potential energy use, oil use, and carbon dioxide emissions of advanced light-and-heavy-duty vehicle technologies. Two excel workbooks comprise the model, one is a Base Case of U.S. highway fuel use and carbon emissions to 2100 and the other is a copy of the Base Case that can be modified to reflect advancements in vehicle and alternative fuel markets (Argonne National Laboratory, 2014).

Walk Score/Transit Score/Bike Score

Walk Score is a simple commercial tool that calculates the relative walking accessibility of a home to various commercial activities. This score is often made available to real estate agents and their customers to inform residential location choice. Walk Score and related ad-hoc tools have also been used by academics as a convenient and comparable metric of sustainable neighborhood design. Similarly, TransitScore and BikeScore calculate accessibility via transit and bicycle respectively (Data Services, 2014).

5.6 Use of Models and Support Tools in Existing University Courses

For the most part, the tools described in this section are not widely taught in the courses previously identified in this report. This does not necessarily imply that these courses do not teach practical frameworks. For example, the planning courses at the University of California campuses regularly make use of tools and guidebooks written for California-specific policies. But little is done with respect to the national scope. The most widely studied tools in the courses reviewed were energy and emissions models, particularly GREET and MOVES.

6. Current Research in Sustainable Transportation Education

The research team conducted a keyword search of journal papers to assess the topics that are currently being addressed by the research community in sustainable transportation education. Searching for the term "sustainability transportation education" in the Transportation Research International Database (TRID) identified 470 articles, across 38 journals. The ten reoccurring journals included: International Journal of Sustainability in Higher Education; Journal of Professional Issues in Engineering Education and Practice; Policy, Planning, and Practice; Environmental Science and Technology; Urban Policy and Research; Journal of Planning Education and Research; International Journal of Sustainable Transportation; ITE Journal; Journal of Architectural Engineering; and Transportation Research Record (Journal of the Transportation Research Board).

The keyword index terms from the first 100 articles were used to create another word cloud (Figure 6). Similar to the course topic word clouds (Figures 3 and 4), "transportation," "environmental," and a form of the base word "sustainable" are some of the most frequently word/topics in recent published research. However, the word "planning" appears to be used more frequently than "environmental," indicating a possible needed shift in sustainability transportation education topics. The frequent use of the words "development," "construction," "highways," "transport," and "freight," which are associated with infrastructure design and planning, further supports a research emphasis on planning concepts in sustainable transportation.

Figure 6. Word Cloud of Keywords in Current Research in TRID

7. Educating Future Employees (Jobs in Sustainable Transportation)

A commonality across all universities that offer transportation planning and engineering programs is the training and education of the future workforce. The team assembled keywords from state department of transportation (DOT) websites that have a sustainability program or sustainability manager, and conducted a search for job vacancy descriptions of these sustainability program employees. The team evaluated the online materials for the state DOTs mentioned in the Transportation Planning for Sustainability Guidebook released by the US DOT Federal Highway Administration (2011): Oregon, Delaware, Tennessee, Florida, Pennsylvania, Vermont, California, Illinois, Texas, Minnesota, Washington State, Washington D.C., Montana, New Jersey, New York and North Carolina. The resulting word cloud is presented in Figure 7.

The employment word cloud is very different than the word clouds generated from course topics and research topics. There are no words that stand out as significantly as previously noted in course topics word (transportation, environment, and sustainable) or in the research topics word cloud (transportation, planning, and sustainable). The words with the greatest frequency in the employment word cloud are “green,” “experience,” “planning,” and “policy”. Interestingly, a variety of policy and regulation names are visible in the employment word cloud. For example the words “LEED,” “energy conservation code,” “Clean Air Act,” “NEPA,” and “CFR,” indicate that potential employees must be familiar and proficient with these regulations and manuals. Interestingly, while the word “policy” was prevalent in the course and employment word clouds, it is not as significant in the research word cloud, suggesting potentially important differences in focus. On the technical side, software names are visible in the employment word cloud, including “CAD,” “GIS,” “Micro Station,” “Microsoft Word,” and “Excel,” as well as the slightly smaller words “MOVES” and “CAL3QHC”. Proficiency in these software packages may be critical to Departments of Transportation to quantify progress in a professional manner.

Figure 7. Word Cloud of Keywords in Selected State Department of Transportation Job Announcements

8. Developing a Sustainable Transportation Education Program

This chapter contains a preliminary outline of sustainable transportation concepts, informed by the existing content of academic courses, textbooks, and practical tools presented in earlier chapters of this report. These are topics that should probably be considered for integration into a series of courses and course modules. Focus is given to elements that are not already considered prerequisites in transportation planning or engineering programs, which should at a minimum include transportation statistics, transportation planning, traffic engineering and operations, and roadway design. The list is not intended to be comprehensive, but to serve as a starting point for further discussion and debate in the development of courses:

8.1 Potential Course Topics

Infrastructure Systems

- Earth systems, natural resource utilization, and scarcity
- Urban system sectors (agriculture, industry, commerce, housing, and public services)
- Communications networks
- Transportation systems (information, freight, services, and people)
- Rural and tribal transportation
- Energy and environment as a complex system
- Energy and natural resource flows
- Water resources, drinking water, storage, treatment, and use
- Sewage and water treatment
- Solid waste disposal and recycling
- Energy systems, fuel supplies, and distribution networks (petroleum, LPG, natural gas, electricity, biofuels, hydrogen, etc.)Energy consumption
- Social neighborhoods and livability
- Wildlife ecology and management
- Road networks and landscape fragmentation
- Infrastructure condition assessment
- Design, construction, operation, and renewal of civil engineering systems
- Interdisciplinary nature of transportation problems and solutions
- Problem solving and design in engineering and planning

Sustainability

- Population growth and Malthusian analysis
- Natural resource depletion and degradation
- Climate change and adaptation (weather extremes, sea level rise, infrastructure inundation, etc.) and future changes to engineering design (cross-sections, drainage and erosion, materials, structures, location engineering, etc.)
- Sustainability definitions
- Environmental, economic, and social sustainability
- Sustainability metrics and indicators
- Identifying and pursuing sustainability goals

Urban and Transportation Economics

- Urban economics
- Domestic and international supply chains and supply chain management
- Manufacturing and transportation
- Economics of freight operations
- Impact of regulation and deregulation on the airline, railroad, and trucking industries
- Resource economics, externalities, and pricing
- Regulation, taxes, and market incentives for managing the environment
- Transportation impacts on economic development
- Social benefit-cost analysis and valuation methods, including net present values, asset valuation, natural resource valuation, and damage valuation
- Costs of owning and operating personal vehicles
- Benefits of mobility to the economy and stakeholders
- Physical characteristics, materials balance, and costs of owning and operating urban, suburban, and rural transportation infrastructure subsystems:
  concretes and pavements, construction materials, sidewalks and pedestrian pathways, local roads, arterials and collectors, bicycle infrastructure, freeways and ramps, bridges, traffic operations centers, parking facilities, airports, utilities, pipelines, railroads, urban bus transit, express bus transit, school bus transit, paratransit, urban rail transit, regional rail transit, fuel distribution systems, emergency response systems, communications systems, solid waste transportation systems, etc.
- Methods for lifecycle analysis (LCA) and lifecycle cost analysis (LCCA)
- Transportation asset management

Land Use Planning and Sustainability

- Factors affecting the evolution of urban form and decentralization
- Commutersheds: locations, land use, transportation, and demographics
- City planning processes
- Land use plans, codes, zoning, and regulations
- Schools and residential choice
- Urban growth boundaries and farmland/open space preservation
- Environmentally-sensitive growth management
- Contemporary land use planning and modeling
- Applied analysis of transportation and land use data
- Sustainability in community planning and design
- Neighborhood development (LEED)
- Smart growth, infill development, town centers, and urban renewal
- Corridor-based development and re-development strategies
- Small town and edge city evolution and redesign for sustainability
- Implications of changes in land use or commercial activity on freight movements

Transportation Planning and Sustainability

- Transportation plans, programs, and projects
- Transportation forecasting models and integration with land use and simulation models

- Incorporating sustainability principles and objectives in transportation planning, transportation plans and transportation improvement programs
- Planning and policy evolution over time
- Transportation safety
- Travel demand, travel behavior, mode choice, and sustainability metrics
- Transportation mobility, connectivity, and accessibility analysis by mode
- Parking policy and design
- Considering maintenance and renewal in transportation plans and policies
- Multimodal transportation planning and design (integrated design for pedestrians, bicycles, transit, etc.)
- Context sensitive and innovative design
- Intelligent transportation systems
- Integrated freight logistics planning
- Project evaluation and prioritization methods
- Financing sustainable transportation investments
- Public involvement
- Disruptive transportation technologies

Transportation System Performance

- Transportation performance measures
- Traffic congestion
- Data for planning and evaluation (Census data, surveys, traffic counts, speeds, etc.)
- Infrastructure condition assessment methods and performance prediction models
- Travel demand and traffic operations analysis tools (sketch-planning tools, travel demand modeling, deterministic highway capacity manual traffic flow tools, traffic signal optimization tools, ramp metering, macroscopic, mesoscopic, microscopic traffic simulation, etc.).
- Assessing the traffic impacts of regionally-significant projects
- Transportation demand management and infrastructure improvement strategies (including ride-sharing, car sharing, pricing and tolling, managed lanes, etc.)
- Dynamic optimization
- Uncertainty and sensitivity analysis
- Feedback into the planning processes

Transportation Modes

- Surface transportation
- Marine transportation
- Aviation
- Multimodal planning and assessment

Transportation Impact Assessment (Environment, Economic, and Social Impacts)

- Property rights, governance, and governing the commons
- Ethics, distributive justice, environmental justice, social and transportation equity, etc.
- Stakeholders in sustainable transportation

- Politics and policymaking
- The Americans with Disabilities Act
- Policies for addressing vehicle dependence
- Environmental policy analysis and social and cultural impact assessment frameworks
    - Social and cultural impact assessment tools
- Environmental legal and regulatory framework (Section 4f, National Environmental Policy Act, Endangered Species Act, National Historic Preservation Act, Clean Water Act, wetlands permits, air quality conformity, California Global Warming Solutions Act of 2006, etc.)
- Transportation energy, energy security, and alternative fuels (across all modes, specifically including intermodal transit systems and intermodal freight systems)
- Assessing the environment, economic, and social effects of transportation projects
    - Engine and vehicle technologies
    - Transportation systems, vehicle emissions, and air quality
    - Carbon footprint analysis
    - Climate change modeling and impact assessment
    - Noise impact assessment
    - Transportation systems, water resources, and aquatic ecosystems
    - Subsurface conditions
    - Aesthetics and streetscapes
- Transportation construction logistics and materials specifications
    - Green building design and construction practices
    - Roadsides, vegetation, and environmentally friendly landscaping
- Infrastructure retirement and decommissioning
- Environmental risk assessment and health impact assessment

Sustainability Education and Outreach

- Tools and methods needed to support sustainability planning
- The role of transportation agencies in a sustainable society
- Case studies to highlight best practices
- Sustainability messaging, outreach strategies, and social media

Given the topics identified above, some of the five-week (or ten-week) course modules currently under consideration include:

- Urban infrastructure systems and sustainability
- Environmental and social impact assessment
- Urban economics and resource economics
- Land use planning, transportation planning, and sustainability
- Sustainable transportation policy
- Transportation system performance
- Asset management for sustainability analysis
- Transportation and energy
- Transportation and air quality

- Transportation impact assessment (environment, economic, and social impacts)
- Sustainability education
- Sustainable freight systems and goods movement
- Sustainability modeling tools
- Case studies in transportation sustainability

8.2 Course Development Goals

As discussed in the introduction, the National Center for Sustainable Transportation is embarking on the development of a series of eight sustainable transportation courses over the next four years. Based upon the review of models and existing course materials, much of the focus of these new courses will likely be on teaching practical ways to analyze the impacts of transportation systems on environmental, economic, and social sustainability. Each course will be constructed in three five-week modules, so the elements can be mixed and matched as desired. Once developed (2015-2017), the course materials will be freely available to any university for use in undergraduate or graduate programs.

The first logical step in developing the series of sustainable transportation courses is the creation of course syllabi and module instructional plans. For each module and subsequent lesson, the NCST team will develop instructional goals, proposed pedagogies, readings, assignments, etc. The team did not interact with faculty outside of NCST partner universities in developing the list of primary topics. However, the team will ask for the assistance of faculty at other universities identified in this report to review and comment on proposed course syllabi and lesson plans.

At least two courses over the next two years will be offered to professional planners and engineers through the Georgia Tech Professional Education program (Georgia Tech PE, 2014a) at the Global Learning Center (Georgia Tech GLC, 2014). Faculty from Georgia Tech and the NCST partner universities will create the lectures, using the professional production facilities and support from Georgia Tech's Professional Education staff. Once completed, the professional education courses will be made available at Georgia Tech and possibly by the University of Southern California and California State University, Long Beach professional education partnership. Georgia Tech will also pursue the development of a certificate program in Sustainable Transportation (Georgia Tech PE, 2014b).

Some of the university courses will be designed around the traditional classroom model. Other courses will be constructed in a "flipped" format, where most of the lectures are delivered via videos that students can watch outside of class time. Flipped courses allow the bulk of classroom hours to be spent on discussions, quick-response lectures (short pre-prepared or off-the-cuff lectures conducted in response to questions arising during discussions), case-studies, and problem-solving. Flipped courses provide time to dig more deeply into the material. For example, sustainable transportation courses at the University of Washington all employ the "flipped" format, where a typical class has two hours of video lecture for the week, and students view the videos a few days before a "live" lecture that covers additional materials, questions, comments, student presentation, quizzes, and other activities (Rutherford, 2015).

Sustainable transportation topics are complex, and are generally well-suited for more in depth discussion and hands-on activities; hence, a flipped version of certain materials makes sense. The team also plans to integrate some of the more innovative learning elements identified in the literature review of courses, including: discussion sections, debates, games, and scenario analysis.

Courses will integrate the three sustainability principles (environment, economic, and social) across all three transportation activities (policy and planning; design and construction; operations, maintenance, and end-of-life). These courses will also integrate practical analytical frameworks and modeling tools.

9. Conclusions and Recommendations

After reviewing existing academic courses, research literature, and current industry hiring practices, the team compiled a list of potential modules and course topics that could be integrated into a more comprehensive transportation sustainability education program. Academia and industry currently focus primarily on environmental sustainability, but the professional workplace is also focused on the integration of planning and policy issues. Developing materials that reach deeper into topics in transportation economics (to assess the costs of design, construction, operations, maintenance, and end-of-life stages), social sciences, design, and construction will help students understand the interdisciplinary nature of transportation sustainability. Professionals should be looking beyond the traditional, and often isolated, fields of civil engineering, city planning, and public policy to help students understand sustainability concepts. Transportation planners and engineers need to collaborate with experts in economic analysis and social behavior on course development for transportation professionals.

Using the information gleaned from the review of existing sustainable curricula, the team has outlined a set of sustainable transportation topics for consideration in course development, as well as potential course delivery methods. The delivery methods currently used in NCST university courses include some innovative elements, such as discussion sections, field labs, simulation/gaming, and scenario analysis. Additional research could be undertaken to monitor student success with respect to course delivery method. The interdisciplinary nature of both sustainability and transportation engineering makes it imperative to partner with experts in disciplines outside of engineering and city planning, such as economists, architects, and other social scientists. The following sections explain each recommendation in greater detail.

9.1 Existing Themes and Delivery Methods

One goal of this report is to describe existing courses, textbooks, and tools that can inform the creation of a program of sustainable transportation courses. The review found numerous courses that cover topics related to sustainability, but the scopes of these existing courses are weighted heavily towards planning and policy. The course reviews reported in Chapter 3 of this report also indicated that existing courses tend to emphasize environmental issues in sustainability. With regard to interactions between transportation and other natural and manmade systems, energy has received significant attention, but other resources such as water and rare earth consumption have not.

The existing courses offered by NCST partner universities that cover sustainable transportation topics feature a wide variety of delivery methods, including lectures, debates, and student presentations. Assessment of student performance also differs considerably across courses and programs. The relative effectiveness of the various pedagogies being used in teaching sustainable transportation warrants further evaluation.

9.2 Future Directions and Topic Areas

The analysis presented here suggests that the new curriculum should strengthen the emphasis on economics, systems analysis, modeling, and social sciences. The lack of discussion on social sustainability was evident in Figures 3 and 4. The white space of undergraduate- and graduate-level courses in the “social” column shown in Figure 2 also indicates that social sustainability may not be addressed sufficiently in existing courses. Courses in the social sciences may help strengthen education for sustainable development (ESD) as a whole (Arbuthnott, 2009):

> *Most importantly, ESD curricula should include social science courses to educate students on effective behavior change strategies. Courses in environmental or conservation psychology would satisfy this requirement, as would those in several other social science disciplines.*

Similarly, Figure 2 indicates that there is also room for growth the area of in economic sustainability, especially in the design and construction, and the operations, maintenance, and end-of-life stages. These courses may already exist, but they are more likely to be offered in construction, business, management, and/or economics departments. There is a need to collaborate with other disciplines and perhaps to tailor existing general courses in these areas to the transportation subject area.

9.3 Need for Integrated Approaches

A grand challenge in teaching sustainable transportation is to enable students to think holistically about sustainability throughout the entire transportation system lifecycle. This challenge was also acknowledged in the organization of transportation agencies, and as a strategic issue facing the transportation community as a whole. NCHRP Report 750 Volume 4: *Sustainability as an Organizing Principle for Transportation Agencies* (Booz Allen Hamilton, 2014) puts it this way:

> *Triple Bottom Line (TBL) is an integrated rather than a stand-alone concept: TBL is not exclusive to any one policy area or system. Given the integrated nature of transportation with the rest of human activity, it is difficult to view the transportation system in isolation. Sustainable transportation requires considering a broad definition of sustainability that considers how transportation affects overall social sustainability and how other policy areas need to be coordinated to achieve sustainability.*

Existing modeling tools (Figure 5) appear to take a more integrative approach in evaluating sustainability than the way in which courses are currently being taught. Covering both content breadth and depth is difficult, given the limited time and resources of a course. Therefore, it may be advantageous to take an integrative approach at the programmatic level, so that different courses within a program can collectively address the challenges of sustainable transportation.

An integrated approach also requires the consideration of interactions between the transportation system and other systems, and, most importantly, proper methods and tools to quantify sustainability in a consistent manner.

9.4 Concluding Remarks

Given that basic economic productivity, environmental quality, and social equity concepts are already central in courses in transportation planning, transportation engineering, public policy, and other disciplines, there is a risk that explicit courses in "sustainable transportation" may be redundant to existing courses. The first step toward building a sustainable transportation curriculum within a university is to take an initial census of sustainability-related courses across all disciplines within the institution. Identifying courses offered in departments outside of civil engineering and city planning broadens the range of course options available to students. Furthermore, "sustainability" cannot be readily compartmentalized into a separate discipline, as the three pillar concepts permeate most engineering, planning, and policy disciplines.

With these concerns in mind, the NCST plan is to develop a series of eight modular courses that focus on sustainability within a transportation engineering framework, but that contain significant interdisciplinary content in planning and policy. These courses will be comprised of modules that instructors may use in an *a la carte* fashion to strengthen the sustainability elements of their own courses, or to develop new courses with particular emphases. The goal of the sustainable transportation education project is to develop materials that will produce graduates (and train practitioners) who are capable of using and improving the analytical tools for transportation sustainability assessment that are regularly used in practice. The modular structure provides both breadth and depth into sustainable transportation topics. The eight modules will cover a sufficiently broad range of topics. Each module will focus on a specific topic to ensure students gain deep understanding and master the skills required to analyze real-world problems related to the module topic.

Establishing new sustainable transportation education goals for university education and professional development is important, given the current number of analytical tools and frameworks designed for practitioners, and posted career opportunities identified through agency job announcements that appear to require modeling expertise. The primary audience for the NCST courses are the professionals who are currently, or soon will be, encountering the problems that these tools were designed to assess. Hence, it is important that courses prepare technically competent graduates who understand the cause-effect relationships at work and know how to perform analyses and apply models to quantify the impacts of alternative transportation plans and programs. The advent of comprehensive sustainability textbooks also provides an opportunity to acquaint student populations from across the nation with a common philosophical framework and language to address sustainability issues, should these materials be adopted into existing courses or selected as the structure of new courses.

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