

**Life-Cycle Assessment in Government Policy
in the United States**

**A Dissertation Presented for the
Doctor of Philosophy Degree
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ABSTRACT

The United States government, both at the federal and state levels, is continuously relying on emerging technological and methodological tools in order to provide essential information to decision and policy-makers. Life-cycle assessment (LCA) is a rapidly emerging tool for both the private and public sectors. Governments around the world are looking towards life-cycle information to guide policy and promote environmental issues. LCA began in the United States in 1969 when the Coca-Cola Company wanted an innovative way to evaluate the impact of their beverage container's impact on the environment. Since then, life-cycle concepts in the U.S. have been slow to be adapted and accepted for various reasons.. While the use of LCA in the development and application of policy is more common in Europe, the U.S. has started to look towards the possibilities of life-cycle information for policy decisions at both the federal and state levels.

The first essay in this dissertation introduces life-cycle assessment and describes the methodology. The remaining essays present some insights into the value of life-cycle information inside of government policy by looking at its evolution and history (Chapter 2), illustrating the types of information LCA provides (Chapters 3 and 4), and providing policy implications and identifying opportunities for the future of LCA inside of policy in the United States (Chapter 5).

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CHAPTER 1 – INTRODUCTION: LIFE-CYCLE ASSESSMENT

1.1 Background

Life-cycle concepts in the United States emerged after an influential study initiated by the Coca-Cola Company in 1969 on their bottle products. Coca-Cola was interested in more than just the end-use environmental impacts of their bottles, but also the impacts associated with the raw materials production and the manufacture and transport of the bottle. This type of perspective on environmental impacts was the first of its kind and served as the impetus for life-cycle thinking in America.

The newly established Environmental Protection Agency (EPA) soon became interested in life-cycle information after seeing the Coca-Cola study. At the time, waste stream and energy efficiency concerns drove EPA to pursue new ways to evaluate environmental impacts of products and systems. Since these concepts first emerged in 1969, shifting public interest affected the speed and intensity of developing life-cycle science. For example, EPA first became interested in life-cycle methodologies as a way to evaluate product waste-streams (driven by the public's concern about landfilling) and energy efficiency (driven by the oil/energy crisis of the early 1970s). However, as the energy crisis was ending and other broad environmental regulations such as the Clean Water Act and Clean Air Act were showing positive environmental results, the advancement of life-cycle evaluation of products slowed. It was not until the 1990's when waste management and landfilling became a major public concern again that life-cycle concepts made significant advancements. "Life-Cycle

Assessment” or “LCA” was coined during this time and standards and methodology development were the major contributions from LCA practitioners, EPA, and industries. In the 2000’s, concerns with climate change and green house gas (GHG) emissions have further incited interest in life-cycle evaluation. A more comprehensive look at the history of LCA in the United States is presented in Chapter 2.

1.2 Life-Cycle Assessment

Life-cycle assessment (LCA) is a holistic approach for assessing the environmental impacts of products over some or all of their life-cycle from raw materials collection to disposal. There are four primary phases of LCA: goal and scope definition, inventory analysis, impact assessment, and interpretation. The goal and scope definition phase describes the purpose of the study. The products to be considered and system boundaries (e.g., what unit processes will be included in the study) are defined at this point. Inventory analysis (LCI) creates a list of flows from and to nature from the system process. In other words, the inventory phase is the collection of input data for the unit processes under study. There can be hundreds of inventory flows depending on the system boundary and functional unit of the process or product being examined. Impact assessment organizes and quantifies the inventory results into relatively few general categories such as global warming potential ($\text{CO}_2\text{-eq}$), acidification (H^+ moles-eq), eutrophication (N+P-eq), and respiratory effects ($\text{PM}_{2.5}\text{-eq}$). Impact assessment can involve sensitivity analysis and consistency checks that

contribute to the discussion of final conclusions, limitations and recommendations. Each stage allows for interpretation in order to determine levels of confidence in the final results in order to communicate the results. The relationship of how these four phases work together is shown in Figure 1.

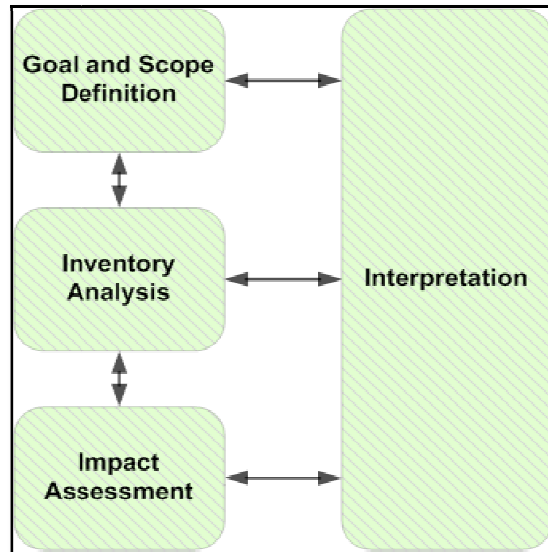


Figure 1 Phases of Life-Cycle Assessment

1.2.1 Life-Cycle Assessment in Government Policy

The United States is only slowly starting to integrate LCA into public policies relative to governmental policy in Europe. Europe, for example, has included LCA into many types of public policy such as battery recycling, chemicals regulation, electrical and electronic equipment, and other hazardous materials (European Commission 2012). In the U.S. the only substantial integration of LCA into a federal public policy is the Energy Independence and Security Act of 2007 (EISA). LCA was chosen as the method to determine if

threshold for emissions standards reductions for newly-introduced biofuels are met.

Even without direct legislative policies that direct use of LCA, EPA uses life-cycle concepts inside of various administrative programs through their Center for Life-Cycle Assessment Research inside the Risk Assessment Research division. EPA has been instrumental in the development of standards and the refinement of methodologies, particularly methods based on U.S. conditions. EPA developed the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). TRACI categorizes impact assessment methodologies specifically for the U.S. using “input parameters consistent with U.S. locations for the following impact categories: acidification, smog formation, eutrophication, human cancer, human non-cancer, and human criteria effects” (EPA 2012). TRACI is very commonly used in government and private impact assessments and is a component inside many LCA software packages such as SimaPro.

State environmental protection agencies are beginning to use life-cycle concepts in their own decision-making. For example, California recently passed a law requiring life-cycle assessment of the state’s used lubricating and industrial oil management processes. The state of Oregon has also recently started the development of greenhouse gases inventory using life-cycle methods. A more careful examination of the use of LCA in state and federal policy is described in Chapter 5.

1.3 Objectives and Chapters Overview

The study objectives were to:

1. assemble the historical events of life-cycle assessment and its role in government policy in the U.S.
2. develop a life-cycle inventory of wood fuel pellets manufactured in the southeastern U.S.
3. develop a life-cycle inventory of switchgrass pellets manufactured in the Southeastern U.S.
4. investigate the opportunities for the integration of life-cycle assessment in existing and future American governmental policies

Each of these objectives is individually addressed through separate chapters in this dissertation. Each chapter presents a discussion of the objective, relevant literature, data used, and discussion of implications. The following paragraph offers a brief overview of each chapter's focus.

Chapter 2 offers a historical synopsis of LCA in the United States and speculates on the future of LCA's integration inside of U.S. policy. Chapter 3 develops a gate-to-gate life-cycle inventory of wood fuel pellets produced in the southeastern United States and discusses a preliminary impact assessment based on the inventory collected. Similarly, Chapter 4 develops a cradle-to-gate life-cycle inventory of switchgrass fuel pellets in the southeastern United States and discusses a preliminary impact assessment based on the inventory collected on the growth and harvest of switchgrass combined with the pelletization

process. Chapter 5 explores some opportunities for LCA's integration into existing American legislative policy as well as identifies administrative policy strategies for LCA at the Environmental Protection Agency. Chapter 6 summarizes the final conclusions of each research objective.

CHAPTER 2 - LIFE-CYCLE ASSESSMENT IN AMERICAN POLICY: PAST, PRESENT, AND FUTURE

2.1 Abstract

Life-cycle assessment (LCA) is an emerging in America to be an important tool for evaluating environmental impact. Private industries initiated the use of LCAs to evaluate the environmental burden of their products and processes. Policy-makers and government agencies are increasingly recognizing LCA as a way of evaluating greenhouse gas emissions and waste streams. Currently, the most significant application of LCA in policy development and application is through the Energy Independence and Security Act of 2007 (EISA), which mandates the use of life-cycle analysis on new renewable fuels introduced to replace traditional fuels. Life-cycle assessment was the method chosen by this legislation to determine if renewable fuels provide significant benefits.

This chapter summarizes the history of life-cycle thinking in America and how policy makers have adopted that thinking as well as some lessons learned from this history. The initial emphasis is on private industry's voluntary involvement in life-cycle practices because this is how LCA started. This chapter includes a timeline that summarizes LCA's influence on policy and/or government actions. A compilation of U.S. policy documents, agency actions, journals and publications, software developments, and LCA developments in private industry is presented.

2.2 Life-Cycle Assessment in American Policy: Past

Life-cycle thinking is now widely encouraged, implemented, and in some applications mandated through policy in Europe. For this reason, it could be assumed that LCA had its beginning in Europe and migrated to America. In reality, comprehensive environmental life-cycle assessments were conceived independently and concurrently in the late 1960s and early 1970s in the United States and in Europe (Hunt, Franklin et al. 1996). Early on, life-cycle research was pursued by private interests and only later caught the attention of U.S. governmental agencies.

In 1969, the Coca-Cola Company commissioned a study of beverage container options that initiated the concept for the standard methodology for life-cycle inventory of environmental inputs in the United States (Scientific Applications International Corporation 2006). The Midwest Research Institute (MRI) conducted this first LCA study in 1969 on Coca-Cola's behalf. This study was not published because of the confidential nature of the data; however, it "laid the foundation for the current methods of life-cycle inventory analysis in the United States" (Scientific Applications International Corporation 2006).

The Coca-Cola Company wanted to know the environmental impacts of their different beverage containers in order to choose the container with the least environmental impact. This was the vision of Harry E. Teasley Jr., the manager of the packaging function at Coca-Cola (Hunt, Franklin et al. 1996). Other companies followed this example and performed such *comparative life-cycle*

inventory analyses for their respective products in the early 1970s. This venture captured the attention of the U.S. Environmental Protection Agency (EPA), which was looking into ways to reduce waste streams and strengthen recycling programs.

EPA then became involved in the refinement of the methodology used in the Coca-Cola study (Svoboda 1995). This refinement led to the first term for the type of analysis being done: *resource and environmental profile analyses* or REPAs. It was not until the 1990s that this terminology changed to *life-cycle assessment* or LCA. In Europe, these same ideas were being referred to as *ecobalance* (Scientific Applications International Corporation 2006). However, the core principles of life-cycle information, both in the U.S. and Europe, were the same. A historical timeline of LCA activity in the United States is presented in Table 1.

Table 1 Historical Timeline of LCA activities in the United States

1969	Coca-Cola Company commissions first of its kind study to MRI on life-cycle environmental impacts of beverage containers
~1970	The term “Resource and Environmental Profile Analysis (REPA)” was coined for life-cycle studies by the Environmental Protection Agency (EPA)
~1971	Mobil Chemical Company commissions similar study (REPA) on life-cycle environmental impacts of polystyrene foam meat trays
~1971	Stanford University engineering students known as “Ecology House” study life-cycle information on beverage industry
~1971	MRI commissioned by the President’s Council on Environmental Quality to perform a series of REPAs on recycling of various materials
~1972	Bruce Hannon (University of Illinois) publishes technical report of life-cycle information on system energy and recycling of the beverage industry (Hannon 1973)
1972	Arsen Darnay, Deputy Assistant Administrator for solid waste at EPA initiates landmark REPA study by MRI to complete on beer and soft drink containers
~1974	A framework for impact assessment was established and REPA methodologies go public for the first time
1974	EPA produces public report, “Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives” marking the entry of REPA/LCA concepts in the public domain in a peer reviewed document for the first time
1975	Franklin Associated, Limited (FAL) forms and starts to conduct REPA studies full time with the help of Bob Hunt
~1975	EPA initiates a REPA on disposable products with MRI and milk containers with both MRI and FAL
~1975-76	EPA shifts focus to decide that life-cycle information as a regulatory tool was impractical; EPA stops initiation of REPA studies of products
~1976	The United States energy crisis shifts the focus of life-cycle information towards energy portions of REPA/LCA studies; U.S. Federal Energy Agency commissions Research Triangle Institute along with Franklin Associates to perform economic and energy studies outlining comprehensive databases and explanations of methodologies into public domains

~1976-80	After 1976, following the EPA's decision to shift their focus on LCA/REPA, private companies began to commission scientific reports on products in hopes to produce with a lower environmental burden; these reports were largely held confidential
1978	Goodyear Tire and Rubber Company uses study on 2 liter plastic (PET) containers in marketing campaign to illustrate their containers were no more environmentally burdensome than their competitors
1980	Solar Energy Research Institute (DOE laboratory) issues life-cycle report into public domain that consisted of a comprehensive peer reviewed REPA database on major commodity raw materials
~1981-1988	REPA/LCA studies during this period primarily consist of commissions from private businesses and trade associations; this period allowed for life-cycle administration to be fine-tuned and for databases to be expanded (slowly)
1988	Solid waste issues dramatically bring REPA/LCA concepts back into the public light; public interest drive REPA concepts to tackle recycling and product reuse in hopes of reducing dependence on landfilling
1990	The Conservation Foundation and the Society of Environmental Toxicology and Chemistry (SETAC) hold panels that discuss the role of REPA in resource and environmental policy; Life-cycle Analysis (LCA) is introduced and marks the official replacement of the term "REPA"
1991	Eleven State Attorneys General in the United States denounce the use of LCA results to promote products until uniform methods for conducting assessments are developed
1991	EPA shifts position back in favor of life-cycle concepts and introduces their focus towards assisting in development of public databases and guidelines for LCA.
1992	Franklin Associates publishes the first complete presentation of LCA methodology to appear in a peer reviewed scientific journal edited in the United States (Environmental Impact Assessment Review)
1993	EPA's Risk Reduction Engineering Laboratory publishes Franklin Associates' (and Batelle) "Life-Cycle Assessment: Inventory Guidelines and Principles"
1994	LCA activity wanes, most likely attributed to the emergence of ISO 14000 Environmental Management standard series, which

	attempted to set international standards on life-cycle development; this largely took LCA practitioners and researchers away from LCA studies in order to work on standards development as well as apprehension by industry during the transition
1995	Jane Bare, a chemical engineer at the EPA recognize the need for a US tool that was not based on European conditions. EPA begins the development of a software tool that used U.S. conditions called the tool for the Reduction Assessment of Chemical and other environmental Impacts (TRACI)
1996	DOE's Office of Energy Efficiency and Renewable Energy (EERE) sponsors Argonne National Laboratory to develop GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) as a tool to allow researchers to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis
1998	International standards (14040 on General Principles, 14041 on Inventory, 14042 on Impact Assessment, 14043 on Interpretation) are published
2001	The American Center for Life-cycle Assessment (ACLCA), a non-profit membership organization forms as a part of the Institute for Environmental Research and Education (IERE), a 501(c)3 organization
2001	EPA publishes Life-cycle Engineering Guidelines to provide leadership for the implementation of life-cycle analysis of engineering products, systems, processes, and facilities
2002	U.S. Department of Defense (DOD) directs National Renewable Energy Laboratory (NREL) establishes U.S. LCI database as a goal to fulfill the need for publicly available LCI data
2002	The United Nations Environment Programme (UNEP) join forces with the SETAC to create the Life-cycle Initiative, an international partnership consisting of three programs: The Life-cycle Management (LCM program), The Life-cycle Inventory (LCI) program, and the Life-cycle Impact Assessment (LCIA) program
2007	United States Congress passes the Energy Independence and Security Act of 2007 (EISA) which for the first and only time in American regulatory policy mandates the use of life-cycle analysis on a product or system; the National Renewable Fuel Standard Program (RFS) mandates that life-cycle greenhouse gas emissions be analyzed for biofuels

2011	National Research Council (NRS) published an EPA-commissioned report on incorporating sustainability at EPA. The report published in 2011, identifies LCA as one of the most appropriate tools EPA should be using to advance sustainability inside of policy options
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“With the formation of public interest groups encouraging industry to ensure the accuracy of information, and with the oil shortages in the early 1970’s, approximately 15 REPAs were performed between 1970 and 1975” (Scientific Applications International Corporation 2006, p. 4). During this period, a consensus was reached among environmental scientists on the general REPA methodology (Hunt, Sellers et al. 1992). Perhaps the most notable REPA study during this time was an analysis of nine beverage container alternatives by Bob Hunt and Bill Franklin et al. initiated and published by the Environmental Protection Agency (Franklin Associates 1993). This study compared environmental impacts during the life-cycle from four basic raw materials—glass, steel, aluminum, and plastic. This marks the first publications by a government agency that recognized life-cycle science; it also marks the first public report of a peer-reviewed life-cycle analysis.

Around the same time that Coca-Cola conducted their study on beverage containers, Ian Boustead in the United Kingdom developed a similar inventory approach later to be known as “ecobalance”. In 1979, Boustead published the *Handbook of Industrial Energy Analysis* (Boustead and Hancock 1979). As in the

United States, as energy issues declined in importance after the oil crisis, so did interest in energy analysis as well as waste management and recycling.

2.2.1 Under the radar

Government agencies showed little interest in LCA during the next five years (1975-1980). While EPA continued to be interested in broad waste management topics and tools that promoted and made recycling more efficient, the agency decided in 1976 that life-cycle analysis was too impractical to implement as a regulatory tool for waste management and recycling (Hunt, Sellers et al. 1992; Hunt, Franklin et al. 1996). EPA's major concern with using LCA as a regulatory tool was the implication that REPA's that would have to be done on thousands of products, which would require a micro-managing regulatory process of private industry.

EPA did not totally abandon LCA concepts but they did focus their interests in energy portions of LCA, "ushering in an era in the U.S. of energy profile studies" (Hunt, Franklin et al. 1996). The decision to focus on energy portions of LCA was made easier by the perceived notions (by the general public and EPA) that progress was being made in environmental issues, especially in regards to emissions reductions by other regulatory means such as the Clean Water and Clean Air Acts. Perhaps because these acts were very visible to the public and the regulatory actions seemed to be addressing the concerns made LCA seem unnecessary for addressing emissions reductions at the time. Energy,

on the other hand, was still fresh in the minds of the government and the public, with the United States having just gone through the oil crisis of the mid 1970s.

Meanwhile, from 1970 to 1980, Franklin Associates performed approximately twenty-five life-cycle inventory (LCI) studies on various products including: beverage containers, soft drink delivery systems, diapers, consumer paper products, meat trays, grocery sacks, egg cartons, plastics, detergents and sweeteners (B. Sauer, Franklin Associates, personal communications, January 17, 2012). One notable REPA study was used by the Goodyear Tire and Rubber Company in 1978 in marketing plastic two-bottles (PET), in an attempt to illustrate that their product was no more environmentally burdensome than that of their competitors (Bider and Hunt 1978; Hunt et al. 1992). This perhaps set the stage for later concerns, in some cases expressed by the government, about how life-cycle information was to be used in public discussions. In the 1990s, concerns about data quality, lack of standardization, and the possibility of misleading marketing led to many reactions among state and federal governments as well as LCA practitioners (Curran 1997).

Following the EPA's shift to a concentration on energy system impacts, the Solar Energy Research Institute, a Department of Energy facility (which became the National Renewable Energy Laboratory [NREL] in 1991), in 1980 commissioned a life-cycle report that estimated the air and water pollutants, and energy consumption, from the production of raw materials used in wind energy systems (Bider, Seitter et al. 1980). This marked the first time, other than the

EPA's involvement in methodology refinement, that a full-scale study was commissioned by a U.S. government agency. Other than this study LCA remained largely in the private sector and confidential. The Solar Energy Research Institute also introduced a public, peer-reviewed REPA database at that time.

While public policy initiatives from 1975 through the late 1980s were not focused on life-cycle thinking, private industry kept life-cycle researchers busy with confidential, commissioned reports. To a large extent, these reports were used in-house because businesses that were interested in environmental impact analysis and reducing production costs were using the information to try to create products with less environmental burden. Industries were using life-cycle information in a way that would benefit their own products (and perhaps also serve their commitment to the environment) by identifying environmental burdens in their product systems. In contrast, EPA and DOE were primarily interested in gathering information that would strengthen efficiency in waste management (landfilling/recycling concerns) and energy systems (Solar Energy Research Institute). This contrast of how and why LCA was being used demonstrates how private and governmental interests can have different goals. Private industries seemed to be interested in making more marketable products at lower costs while government was interested in using LCA to make waste and energy systems more efficient.

2.2.2 Reemergence of LCA

The next period of rapid advancement, particularly in Europe, was the late 1980s and early 1990s (Jensen, Elkington et al. 1997). “The sudden revival of LCA in the late 80’s is difficult to understand. Not only packaging, but also many other products were analyzed from cradle-to-grave” (Klöpffer 1997). During this period, Europe’s LCA development and acceptance far outpaced the United States, particularly in regards to governmental policy incorporation. Life-cycle concepts garnered public attention in 1988 for the second time since the early 1970s (Curran 1996; Hunt, Franklin et al. 1996). Concerns over dependence on landfilling for waste management stimulated public-sector interest in using REPA concepts to tackle recycling and product reuse. This was similar to the motivation for EPA’s first exploration of life-cycle concepts in 1973, with its Interest and involvement in Resource Environmental Profile Analyses. Waste management (landfilling and incineration), public interest in recycling efficiency, as well as concerns about energy efficiency, all contributed to a second attempt at looking at life-cycle science as an informational tool.

At a time when Europe was integrating life-cycle methods into decision-making and policy, federal agencies in the United States were only beginning to accept and explore the merits of life-cycle thinking and science. In 1990, the Conservation Foundation and the Society of Environmental Toxicology and Chemistry (SETAC) convened panels to discuss the role of REPA in resource and environmental policy. What came forth from these proceedings was the term

“Life-cycle Assessment” that replaced the term “REPA” for all intents and purposes, especially in the United States (citation). Around the same time, EPA officially started LCA research efforts and established a new center of research for LCA under the direction of Mary Ann Curran. This action by EPA represented the boldest acceptance of life-cycle information science by a governmental agency. Because of EPA’s new research efforts and public interest in solid waste issues, the next few years produced rapid advancements in life-cycle research in the United States. This surge did not necessarily result in an increase in actual LCA studies—rather a focus on standardization and LCA process improvement and a growth of interest by U.S. government agencies in life-cycle ideas.

In 1991, eleven State Attorneys General in the United States who were concerned about the lack of standardization for LCA, issued a statement protesting against the use of LCA results to promote products until uniform methods for conducting assessments were developed (EPA 2006).¹ In the same year EPA introduced the agency’s focus on assisting in the creation of a public database and issuing guidelines for LCA development. This redirection of EPA’s role in life-cycle development was perhaps initiated by Executive Order 12873 issued by President Clinton in 1993. This order directed the EPA to “issue guidance that recommends principles that executive agencies should use in

¹ In contrast, fast-forward to 2009, the state of Vermont Attorney General, Elliot Burg calls for the accurate emissions advertisement of energy corporations (in this case a Nuclear energy firm, Entergy). Elliot Burg cited life-cycle analysis results of nuclear power to illustrate how accurate emissions should be advertised (<http://www.atg.state.vt.us/news/attorney-general-calls-for-accurate-emissions-advertising.php>)

making determinations for the preference and purchase of environmentally preferable products” (Clinton 1993).

The next few years (1990-1995) were important in the development of guidelines and methodologies of life-cycle analysis. Franklin Associates published the first complete presentation of LCA methodology to appear in peer-reviewed scientific journal edited in the United States in 1992 (Hunt, Sellers et al. 1992). A follow-up publication appeared the next year published by EPA’s Risk Reduction Engineering Laboratory in collaboration with Franklin Associates and Batelle that outlined life-cycle assessment inventory guidelines and principles (Franklin Associates 1993). These publications are important because they were both precursors (at least inside the United States) to the International Organization for Standardization (ISO) 14040-43 standards for life-cycle assessment which emerged a few years later (ISO 2006a; ISO 2006b; ISO 2006c; ISO 2006d).

While ISO standards were being developed, the EPA began work on a software tool that used U.S. conditions. This tool turned into the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) (Bare 2002). This tool allows for impact analyses to be calculated for various impact categories such as global warming potential or ecotoxicity. It is a very commonly used impact assessment method inside of LCA software packages. Concurrently, the U.S. Department of Energy’s Office of Energy Efficiency and Renewable Energy (EERE) sponsored the Argonne National

Laboratory to develop a tool to allow researchers to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis. This tool was first introduced in 1996 and named GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) and placed on the public domain, where it is still available online (<http://greet.es.anl.gov/>). The development of these two life-cycle based tools by EPA and DOE is significant in LCA's history because it marks the first introduction of public, practical tools meant for use by anyone interested in LCA.

In 1998, ISO's standards were published on general LCA principles (14040), inventory (14041), impact assessment (14042), and interpretation (14043). These standards were accepted among the LCA community not only in the United States but also among LCA practitioners and researchers globally. Because of the concern by the Attorneys General of the eleven states and initial focus by the EPA towards guidelines development, the United States' government had an interest in the global standards development. Today, most LCA practices comply with ISO requirements, especially for life-cycle inventory studies that seek to be included in major databases.

Beginning in 2001, the United States began to see the formation of organizations interested in the expansion of life-cycle practices. The most influential of these organizations is The American Center for Life-cycle Assessment (ACLCA), a non-profit membership organization formed by the Institute for Environmental Research and Education (IERE), a 501(c)3

organization (ACLCA 2012). EPA's MaryAnn Curran first brought the idea for the center to the attention of Rita Schenck, the director of IERE. Both Curran and Schenck saw the need for a conference and professional group representing life-cycle assessment. As a government agency, EPA needed a non-profit partner in order to raise funds for such a group—thus the partnership between EPA and IERE was created to establish ACLCA (R. Schenck, personal communications, January 11, 2012). The ACLCA has grown from a professional society that organized conferences and panels to one that issues certification for LCA professionals, leads programs that use life-cycle thinking as the core principles (e.g., environmental product labeling), and provides critical review assistance for LCA studies.

With public and government interest growing for life-cycle environmental impact concepts, consulting firms focusing on LCA started opening in the United States. These firms acted as LCA consulting practitioners and as distributors of LCA software packages. In the mid-1990s and early 2000s, LCA development in America saw a rapid increase of technological tools geared towards life-cycle analysis. The development and widespread use of these newly developed software tools and databases by those interested in LCA approaches, including federal agencies, reflected an increasing acceptance and use of life-cycle science. It also demonstrates the willingness to collaborate in the area of life-cycle information, especially among U.S. federal agencies. In fact, the EPA

published a report in 1995 with the express purpose of providing LCA practitioners with public data sources for preparing LCA reports (EPA 1995).

Continuing with their mission on focusing on guidelines development, EPA published, “Life-cycle Engineering Guidelines” in 2001 to facilitate the implementation of life-cycle analysis in the engineering of products, processes, and facilities (S.C. and Vigon 2001). Around the same time the U.S. DOE directed the National Renewable Energy Laboratory (NREL) to establish a U.S. LCI database to fulfill the need for publicly available LCI data. The resulting Life-Cycle Inventory Database eventually turned out to be the first of a few large databases of life-cycle data specifically tailored to conditions in the United States.

The progression in life-cycle science in the United States along with the development taking place in Europe and elsewhere in the world resulted in a need for international initiatives for the advancement of LCA. In 2002, a partnership was made between the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) to create the Life-cycle Initiative (United Nations Environmental Programme (UNEP) 2002). This partnership developed three programs (Life-cycle Management or LCM program, Life-cycle Inventory or LCI program, and Life-cycle Impact Assessment or LCIA program) with the goal of assisting in the development and dissemination of practical tools for evaluating the opportunities, risks, and trade-offs associated with a product’s life-cycle. This initiative comprised 3 phases. The first phase ran from 2002 through 2006 and concentrated on methods

development. Phase II runs from 2008 to 2012 with a focus on Life-cycle Management (LCM), Social Life-cycle Assessment, Life-cycle Costing, and continued work on tools for methods development. The strategy for Phase III is scheduled for 2013 and 2017 and is currently being developed with the expectation to focus on consumption clusters such as consumer products and food. “Although the Life-cycle Initiative is a global effort, many of its activities have impacted how LCA is done in the U.S.” (B. Vigon, personal communications, January 10, 2012). In this regard, the initiative serves as connecting force between LCA efforts and advancements globally.

2.3 Life-Cycle Assessment in American Policy: Present

To date, the use of LCA in Federal policy (at least in an active way) is limited to two agencies (EPA and DOE) and exists more for technology assessment than for policy formulation (B. Vigon, personal communications, January 10, 2012). While both EPA and DOE use LCA in different capacities, EPA is the only agency that is required (in some way) to perform life-cycle analysis to create regulatory standards through the Energy Independence and Security Act of 2007 (EISA) (110th United States Congress 2007). EISA was passed by Congress and signed into law by George W. Bush in December of 2007. Through revisions to the National Renewable Fuel Standard program (RFS), EISA “established eligibility requirements for renewable fuels, including the first U.S. mandatory lifecycle greenhouse gas (GHG) reduction thresholds, which determine compliance with four renewable fuel categories” (EPA 2010)

EISA requires any new renewable fuels to result in a 20% to 60% reduction (depending on fuel type) in life-cycle GHG emissions compared to the fuels that they are replacing (EPA 2010).

In response to these requirements, EPA conducted a life-cycle analysis of GHG emissions from a variety of renewable fuels. This analysis involved a data review and used a technical outreach program that depended on advice from experts from government, academia, industry and other institutions. EPA also included the consideration of indirect land use change in the inventory analysis required in EISA. In this LCA GHG analysis, EPA stated that they were “confident that it’s modeling of emissions associated with international land use is comprehensive and provides a reasonable and scientifically robust basis for making threshold determinations” (EPA 2010). They were able to make final rules on best available technologies producing ethanol from corn starch, biobutanol from corn starch, biodiesel from soy or waste oils, biodiesel from algal oils, ethanol from sugarcane, and cellulosic ethanol. In all cases, the threshold requirements for GHG reductions were met. Other fuels such as grain sorghum ethanol, woody pulp ethanol, and palm oil biodiesel are on EPAs list to be evaluated using the threshold requirement. The producer of any new technology or fuel can petition EPA to consider their fuel pathway to be eligible for the EISA standard. These petitions are evaluated in the same way and using the same standards as the fuels listed above. The EPA will determine whether the fuel will meet the threshold and make a final rule on its inclusion into the market.

While the legislation requires life-cycle assessments of GHG emissions, including GHG emissions associated with land-use change, it does not require (or suggest in any way) that life-cycle environmental impacts of any other category be examined. Surprisingly, EPA's center for LCA research did not consult in the decision to include life-cycle assessment as a tool in the regulation of new renewable fuels under EISA. More likely, given the language in the bill (EISA), and the focus of the regulations on emission to air, the suggestions may have been provided by EPA's Office of Air and Radiation (OAR) (M. Curran, personal communications, January 9, 2012).

The chronology of how life-cycle methods were included in of EISA highlights the fact that only GHG emissions were being considered. It also suggests that since LCA can be used in various capacities to obtain different information, careful consideration must be taken to make sure LCA is not adjusted or adapted in ways that only address a policy maker's pet concern. The first version of the bill passed the Senate without a specific definition of life-cycle GHG emissions. When the bill reached the House, members in the Energy and Commerce Committee were concerned about whether a Renewable Fuel Standard (RFS) was the best way to reduce GHG emissions. Knowing the final bill would likely have to include a RFS, the House suggested a higher percent reduction of life-cycle GHG emissions (in advanced biofuels) as well as the addition of indirect land use change impacts to be included in the definition of "life-cycle GHG emissions" (L. Schmidt, EPA Office of Air and Radiation,

personal communications, January 20, 2012). Indirect land use change impacts concerned environmental groups because at the time in Indonesia and Malaysia large portions of rain forests were being converted to palm oil biofuel crop production (William 1998). While the inclusion of indirect land use change may have been substantiated with good reasons, it may also illustrate how the use of LCA methodology can be restricted (or in this case directed) to meet specific regulatory requirements.

Similarly, the state of California established a Low-Carbon Fuel Standard (LCFS) in 2001 by Executive Order of Governor Arnold Schwarzenegger². This Executive Order directed the collaboration of the California Energy Commission, California Air Resources Board (ARB), and the University of California to develop protocols for measuring the life-cycle carbon intensity of transportation fuels. These analyses are to be used to develop standards for the State Implementation Plan for alternative fuels (AB 1007, Pavely, Chapter 371, Statutes of 2005). This state action, much like EISA, invokes LCA as an informational tool to aid in the development of standards.

The Department of Energy (DOE) is the other Federal agency that has developed LCA capacities. The first DOE involvement in LCA was in 1998, with the National Renewable Energy Laboratory's (NREL) comprehensive, peer-reviewed REPA database on commodity raw materials. Their second involvement was through the development of GREET. DOE has also required

² Executive Order S-01-07, 1-18-2007, <http://www.arb.ca.gov/fuels/lcfs/lcfs-background.htm>

LCA for developing energy systems technologies since at least the mid-1990s through projects DOE fund; in fact, many of the DOE labs now apply LCA to their research and development efforts and to alternatives assessment today (Vigon 2012). Perhaps the most significant DOE involvement in LCA is the National Renewable Energy Laboratory's (NREL) hosting of the U.S. national life-cycle inventory database (USCLCI database). The goal is a compilation of a national, public, peer-reviewed database of LCI data that can be used for LCA work. The need for a public database was based on the history of LCA development being primarily company-commissioned, proprietary data. This database supports DOE's "Building Technologies Program" which seeks to develop technologies, techniques, and tools for making buildings more energy efficient, productive, and affordable (United States Department of Energy 2012). LCI data for building components is a major component of this database.

While EISA remains the only law that requires the use of life-cycle assessment, there are other governmental entities (many at the state level) that are voluntarily using LCA in their activities (Table 3). Examples include:

- EPA's partnership program "Design for the Environment" coordinates the efforts of industry, environmental groups, and academia to reduce risks to people and the environment. For example, this program has used LCA for the examination of the life-cycle impacts of lithium-ion batteries (Environmental Protection Agency (EPA) 2010).

- The California Environmental Protection Agency, through their Department of Toxic Substances Control, used LCA as a tool for evaluating the impacts of alternative hazardous waste management systems (Boughton and Horvath 2006).
- The Oregon Department of Environmental Quality, working towards their mission of reducing landfill, commissioned a life-cycle inventory analysis of packaging for mail-order items (Franklin Associates 2004)
- The U.S. Department of Agriculture's Forest Products Laboratory has been a supporter of CORRIM, a consortium of academics, industries, and government entities, which has completed many life-cycle studies on wood products.

Table 2 – Timeline of LCA in Government Action (including policy development) in the United States

Government Entity	Year of Action	Policy or Public Action
Environmental Protection Agency	1974	Publishes first peer-reviewed document using REPA/life-cycle concepts on beverage containers (EPA 1974)
Environmental Protection Agency	~1975	Initiates a REPA study on disposable products in collaboration with MRI and milk containers with both MRI and FAL
Environmental Protection Agency	~1976	Shifts focus away from REPA analyses and decides that life-cycle information as a regulatory tool was impractical; stops initiation of REPA studies
U.S. Federal Energy Agency	~1976	Commissions the Research Triangle Institute and Franklin Associates to perform economic and energy studies outlining databases and methodologies into public domain for the first time
U.S. Department of Energy (Solar Energy Research Institute)	1980	Issues life-cycle report into public domain that consists of a comprehensive peer-reviewed REPA database on commodity raw materials
Environmental Protection Agency	1990	EPA officially starts research efforts based on life-cycle concepts again under the direction of MaryAnn Curran
State Attorneys General	1991	Eleven independent State Attorneys General denounce the use of LCA results to promote products until uniform methods for conducting assessments are developed
Environmental Protection Agency	1991	Announces their role with life-cycle assessment to be focused around assisting in public databases and guidelines/methodologies for LCA
Environmental Protection Agency (Risk Reduction Engineering Laboratory)	1993	Publishes Franklin Associates' and Batelle's report on life-cycle inventory guidelines and principles (Franklin Associates and Batelle (1993))

Environmental Protection Agency	1995	Jane Bare leads EPA to recognize need for a U.S. LCA tool not based on European conditions called the tool for the reduction and assessment of chemical and other environmental impacts (TRACI) Bare et al. (1996)
U.S. Department of Energy (Office of Energy Efficiency and Renewable Energy – EERE)	1996	Sponsors Argonne National Laboratory to develop GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) as a tool to allow researchers to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis GREET (19xx)
Environmental Protection Agency	2001	Publishes Life-cycle Engineering Guidelines to provide leadership for the implementation of life-cycle assessment inside engineering products, systems, processes, and facilities
U.S. Department of Energy	2002	Directs National Renewable Energy Laboratory to establish a U.S. life-cycle inventory (USLCI) database as a goal to fulfill the need for publicly available LCI data USLCI
United States Congress (Energy Independence and Security Act of 2007- EISA)	2007	Regulatory policy (Renewable Fuels Standard) mandates the use of life-cycle analysis on any newly introduced renewable fuels that replace standard fuels to determine prescribed threshold standard reductions EISA (2007)
Executive Order of Governor Arnold Schwarzenegger (California)	2007	Executive Order directs the collaboration of the California Energy Commission, California Air Resources Board (ARB), and the University of California to develop protocols for measuring the life-cycle carbon intensity of transportation fuels. These analyses will be used to develop standards for the State Implementation Plan for alternative fuels

State of California	2009	California Oil Recycling Enhancement Act (2009) requires the development of a life-cycle assessment of used lubricating and industrial oil management process.
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California is the only state, however, to have integrated life-cycle assessment as the basis for a statewide policy. The California Oil Recycling Enhancement Act (2009) “requires that the Department of Resources Recycling and Recovery (CalRecycle) coordinate, with input from representatives of all used oil stakeholders, a comprehensive life-cycle assessment of California’s used lubricating and industrial oil management process” (CalRecycle 2012). In short, California wants to know which management method of used oil causes the least impact to the environment. Currently California uses three different management methods to manage over 100 million gallons of used oils: re-refining back to oils for lubrication, distillation to clean ship fuels and an asphalt product, and, most often, combustion for energy (CDTSC 2007). This integration of LCA inside of policy as a tool for management methods may have been inspired by a previous study within California’s Department of Toxic Substances Control. An LCA conducted in 2004 by Bob Boughton at the California Department of Toxic Substances Control on used oil management methods reported that the combustion of used oil might cause 100 times the environmental impact (through heavy metal emissions) of used oil re-refining or distillation (Boughton and Horvath 2004)³.

³ <http://pubs.acs.org/doi/full/10.1021/es034236p>

Since the law's enactment, California has contracted with the University of California at Santa Barbara to administer the comprehensive life-cycle study on the state's used oil management processes. The primary goal of the legislation is to provide an incentive for recycling used oil associated with lubrication and/or oil recyclable oil bi-products as well as to determine the method of processing that will cause the least impact. The life-cycle analysis along with other evaluations of used oil management policies will be reported to the state Legislature on January 1, 2014. This report is expected to provide recommendations for statutory changes that may be necessary to promote increased collection and responsible management of used oil. In other words, the state of California is depending on life-cycle assessment to help shape their used oil recycling program in the future. LCA has been used in other capacities inside the California Department of Toxic Substances Control (DTSC) as well. Along with their previous work on used oil that sparked LCA's integration into California's used oil policy (Boughton and Horvath 2003), this department has used LCA to compare three methods for managing shredder residue to landfilling (Boughton and Horvath 2006) as well as for seeking alternatives to lead wheel weights (CDTSC 2007).

California generates of about 360,000 tons of shredder residue every year, primarily from the shredding of automobiles and appliances to recover iron, steel, and non-ferrous metals (DTSC 2007). This residue is treated with chemical fixatives to reduce leaching of heavy metals into the soil and is transported to landfill sites. DTSC was interested in the chemical treatment and loss of the

material resource and energy value when landfilling. An LCA was performed on three material recovery methods to determine the least environmentally burdensome process. The department was able to show through life-cycle assessment that one recovery method performed, environmentally, better than the others—using shredder residues as fuel and mineral feedstock for cement manufacture (Boughton and Horvath 2006; Boughton 2007). The report provided two major findings: 1) up to 100,000 tons of coal, 100,000 tons of mineral resources, 150,000 tons of landfill capacity, and 50,000 tons of treatment chemicals could be preserved annually (by choosing to only use shredder residues as fuel and mineral feedstock for cement manufacture) and 2) chemical treatments and landfilling shredder waste may have 4 to 10 times higher environmental and human health impacts (than does using residues for cement fuel and feedstock). This report, like the initial report for used oil recycling, was intended to guide decision making for shredding residue methods. While the study was published, California has yet to move forward on changing policy regarding their shredding activities.

Another LCA activity the DTSC is pursuing is for the evaluation of impacts associated with alternatives to lead wheel weights used in California. “Wheel weights are applied to compensate for uneven distribution of weight in vehicle tires and wheels. Approximately 130 million pounds of lead wheel weights were estimated to be on U.S. vehicles in 2003 and projecting in California, the 30 million registered vehicles (circa 2003) may have accounted for 16 million lbs of

lead wheel weights” (CDTSC 2007) This LCA activity in the DTSC was encouraged by a 2009 California state law that charged to reduce lead content in wheel weights to less than 0.1 percent by weight. This restriction of lead pushed for alternatives to be developed to meet a performance criteria set by the law: dense material that resists corrosion, take account for a wide temperature range, be recyclable and cost-effective (CDTSC 2007). Most alternatives that were developed to meet these performance criteria were through the use of steel and zinc alloy. For this reason, DTSC wanted to identify the life-cycle environmental impacts of these alternative products. There were several important findings that could be useful for state decision makers. For example, LCA was able to show that by substituting zinc to replace lead weights only shifted the environmental burdens, as the losses during use are more harmful to the environment than lead. Zinc (as well as lead) had much higher potential health and human health impacts than steel when the weights were lost on the roadway. Finally, these lower impacts associated with steel coupled with the propensity for steel wheel weights to be made from recycled material allowed for steel to be chosen as the best alternative material for wheel weight production (CDTSC 2007).

Another program first instigated by EPA and has since diffused down into state governments is the implementation of “Environmentally Preferable Purchasing (EPP)”. EPA provides services and resources to help federal purchasers buy products and services that are notably sustainable. California, for example, has charged the state EPP Task Force to do that same job for

California state agencies. This task force provides “cradle to grave” or “cradle to cradle” life-cycle evaluations of products such as vehicle fleets, cleaning products, integrated pest management, historic buildings, and releasable classrooms. More specifically this task group relies on a “Technology Development Branch staff that support EPP’s efforts by providing expertise in life-cycle assessment focusing on automotive and truck fleet management, sustainable building, electronic equipment procurement, and statewide master contracts” (CTDSC 2007).

Other states have followed this lead such as the state of Massachusetts through their own EPP procurement program initiated by an Executive Order of Governor Deval L. Patrick (2009). The EPP program in Massachusetts establishes several environmental procurement initiatives, which include: energy efficient products, toxics reduction, recycled content and waste minimization, and sustainable materials. The Executive Order directs for encouraging and prioritizing of goods that are quantified to be sustainably grown, manufactured, transported and handled. The Order specifically names life-cycle analysis as the tool for determining this quantification on various materials including lumber and building materials, organic and locally grown foods, compostable food products, and bio-based products. Not only does this policy encourage sustainable products, it promotes the use of LCA in determining environmentally preferable products. Other states such as Washington, Minnesota, Vermont, Rhode Island, Hawaii are using types of EPP programs that borrow from each other in

determining environmentally preferable products that state agencies purchase. LCA is encouraged in almost all of these programs for comparing and listing products.

In 2004, the state of Oregon became interested in creating a consumption based greenhouse gas (GHG) emissions inventory for their state. “While a few studies have examined the relationship between consumption and greenhouse gas emissions at the national and international levels, this report provides the first such assessment for all consumption within a U.S. state” (SEI 2011). The Oregon Climate Change Research Institute identified consumption as one of the primary drivers of greenhouse gas emissions (OCCRI 2010). In short, life-cycle concepts (a combination of economic input-output and process LCAs) were performed in Oregon to quantify the greenhouse gas emissions associated with all consumption activities. This report is the first of its kind for establishing a life-cycle approach for a state GHG inventory. Life-cycle perspectives were important to Oregon’s efforts because of its ability to identify “hot-spots” in supply chains. The establishment of this inventory and published report in 2011 provided some potential applications of consumption-based GHG inventories. For example, the report identified this inventory as a way to provide useful results to planners focused on extended producer responsibility or “product stewardship” that work with manufacturers to “reduce environmental and health impacts across the entire life-cycle of the product” (ODEQ 2007).

2.4 Life-Cycle Assessment in American Policy: Future

The future use of LCA by the scientific community, U.S. agencies, and subsequently policy-makers in the United States is uncertain. How LCA will be used in public policy depends in part on the ability of the industrial and academic communities to agree on acceptable methods, database reliability, and consideration of technological advancements. There is ongoing debate on many aspects of LCA as an environmental impact assessment tool. Some of these major concerns are: database development, inconsistent and unverifiable data, slow standards acceptance, and concerns about the manipulation of results. Many of these concerns come from different entities (LCA practitioners, industries, government agencies). One example of a concern from private industry is from Rodney Lowman in the American Chemistry Council Plastics Division. He states “LCA results cannot and should not be reduced to a single score that applies to a variety of regions across the board. Therefore, it should be used cautiously in making public policy decisions...” (Lowman 1997).

More and more, it seems that LCA is proving to be a method to bring objectivity, provide alternatives, and set regulatory standards. There are, however, many other concerns that may still slow down LCA’s inclusion inside of policy. LCA is a cumbersome methodology and there are many adjustments that can be made to yield varying results. While standards development have significantly progressed since LCA was first introduced, there still seems to be much wiggle room in how LCA is applied to different systems. For this reason,

LCA might be perceived to be a tool that can be tailored to produce information that supports a decision maker's agenda. Other recent efforts to require reductions in GHG emissions include the "American Clean Energy and Security Act" of 2009 have also focused attention on use of LCA to determine compliance scenarios by energy and other industries. The United States Congress, however, did not pass this particular act.

The history and evolution of LCA does suggest some interesting trends in the development, acceptance, and interest in life-cycle thinking and integration into policy. History suggests that perhaps the most important driver in the advancement and use of LCA—especially in regulatory policy design and formulation—is public interest. Public interest is the main driver for policy creation and it also plays a large role in how that policy is formulated. In the mid-seventies, five years after the life-cycle analysis concept was created, interest in LCA (or REPA at the time) shifted back and forth between LCA focusing on waste management and LCA focusing on energy sources because of public interest shifting between waste management/recycling and the concerns brought on by the oil shortages at the time. It was not until 1988 when, amid reemerging concerns about solid waste disposal, life-cycle information was used to help guide recycling and product reuse efforts and LCA returned to a public forum. Most recently, public interest in climate change has driven the application of LCA to regulate and develop standards for GHG emissions, e.g. LCA was the method

chosen for EISA in creation thresholds for emissions reductions in renewable fuels.

History also suggests that a likely agency to influence whether LCA has a place in policy in the future is the Environmental Protection Agency. In 2010, the EPA commissioned the National Research Council (NRC) to prepare a report on incorporating sustainability at EPA. One of the major undertakings of this report was to identify and elaborate on approaches and tools that should be used to advance sustainability efforts (National Research Council 2011). Along with other tools such as risk assessment and ecosystem services valuation, NRC identified LCA in the list of the most appropriate tools for EPA. MaryAnn Curran at EPA's center of LCA research revealed some important reactions to this report.

Responding to the NRS report, Curran identifies some opportunities, recommendations, education & outreach avenues, and areas of improvement for LCA that fit inside the EPA's mission and goals for the future. These concepts were developed, according to Curran, inside of three LCA-themed meetings in 2011: an intra-agency meeting of EPA management interested in LCA, an inter-agency meeting to address how other Federal agencies are managing data useful for life-cycle thinking, and a "listening session" with diverse stakeholders. These responses are further discussed in Chapter 5. EPA's center for LCA research seems focused on incorporating life-cycle thinking inside of a wide array of EPA activity as an information tool. EPA being such a large agency, LCA and life-cycle thinking has a great potential to be used in a wide variety of agency

policy prescriptions. In this regard, LCA often competes with other informational tools that have been developed specifically for certain areas inside of EPA such as air, water, soil, waste management, conservation, etc.

2.5 Conclusion

LCA's role in US policy development is small compared with Europe, where it is more commonly used for regulatory measures. Because of this, life-cycle practices and data collection on materials and processes are advancing at a much faster pace in Europe. However, as an examination of LCA's history shows, public interest is a clear stimulus for agency actions and policy development. Because of issues related to energy efficiency, climate change and GHG emissions, and waste management, life-cycle information is beginning to play a larger role inside American governmental policy. Policy-makers are beginning to gain confidence in LCA for an informational tool (e.g., the inclusion of LCA as a tool for life-cycle GHG emissions in EISA).

Life-cycle information has seemed to be respected by policy and decision-makers in Europe and other parts of the world and appears to be gaining popularity for policy and decision-makers in the United States. These concerns are not being totally ignored however. UNEP and SETAC's Life-cycle Initiative is using a long-term three phase initiative to standardize and improve life-cycle information particularly addressing using it as a tool for decision and policy-making.

Since LCA is an informational tool, policy-makers and agencies must value the information in order for it to be included in policy and agency action. Public interest may be a stimulus for LCA to be used as an informational tool, but only if policy-makers see that it can help in positively addressing public interests. The inclusion of LCA as a tool to place GHG reduction thresholds (perceivably only concerned with air emissions) to newly introduced alternative transportation fuels inside of EISA is a prime example of this. Public interest at this time was driven by GHG emissions and policy-makers were convinced that LCA could be appropriately used to help address these concerns. However, this inclusion also illustrates how public and political interests influence how LCA is used (in the case of EISA, only for air concerns). This historical synopsis of LCA's inclusion in American government policy can give some indication of the future policy behavior of U.S. federal agencies and policy makers.

CHAPTER 3 - LIFE-CYCLE INVENTORY OF WOOD FUEL PELLETS MANUFACTURING FROM HARDWOOD FLOORING RESIDUES IN THE SOUTHEASTERN UNITED STATES⁴

⁴ A similar version of this chapter has been submitted for publication as:
Reed D., Taylor, A., Bergman R., Harper D., Jones D., Knowles C., Puettmann,
M. Life-Cycle Inventory of Wood Fuel Pellets Manufacturing From Hardwood
Flooring Residues in the Southeastern United States. *Pending Publication*. 2012.

3.1 Abstract

This study presents life-cycle inventory (LCI) data for wood fuel pellets manufactured in the US southeast. Commercial pellet manufacturers were surveyed in 2010, collecting annual production data for 2009. Weighted-average inputs to, and emissions from, the pelletization process were determined. The pellet making unit process was combined with existing LCI data from hardwood flooring residues production, and an impact assessment was conducted using the TRACI model. The potential bio-energy and embodied non-renewable energy in one short ton (the functional unit of this study) of wood fuel pellets was also calculated. The pelletization of wood requires significant amounts of electrical energy (132 kWh per ton; 145 kWh/Mg) but the net bio-energy balance is positive. Wood pellets require 5.5 million Btu (5.8 GJ) of fossil energy to produce 16.4 million Btu of bio-energy. However, if environmental burdens are allocated to the pellet raw material (flooring residues) by value, then the embodied fossil energy is reduced to 2.28 million Btu (2.3 GJ). The pelletization unit process data collected here could be used as in assessment of the environmental impacts of pellet fuel, or when pellets are a pretreatment step in wood-based bio-refinery processes.

3.2 Introduction

There are a number of factors motivating the development of bio-fuels and bio-products: high petroleum prices, a desire for energy independence, the need for rural economic diversification, and concern about the environmental impacts of using fossil carbon sources. With regard to the last point, intuition suggests that products and fuels made from plants inherently have environmental advantages. However, there is growing debate about these potential environmental benefits and more attention is being paid to such matters as the amount of fossil carbon resources consumed in the production and processing of bio-energy and the potential tradeoffs (e.g. between food and fuel) involved. While the environmental advantages of bio-based resources remain important, they can no longer be assumed – they must be demonstrated.

3.3 LCA Methodology

Life-cycle assessment (LCA) is an internationally-accepted way to quantify the impacts and outputs of a product and the corresponding effects on the environment (Hunt et al. 1992; Curran 1993). The International Organization for Standardization (ISO) has published procedures for conducting LCA (ISO 2006). As defined by ISO, LCA is a multiphase process consisting of four interrelated steps (Figure 2):

1. Goal definition and scoping,
2. Life-cycle inventory (LCI),
3. Life-cycle impact assessment (LCIA), and
4. Interpretation.

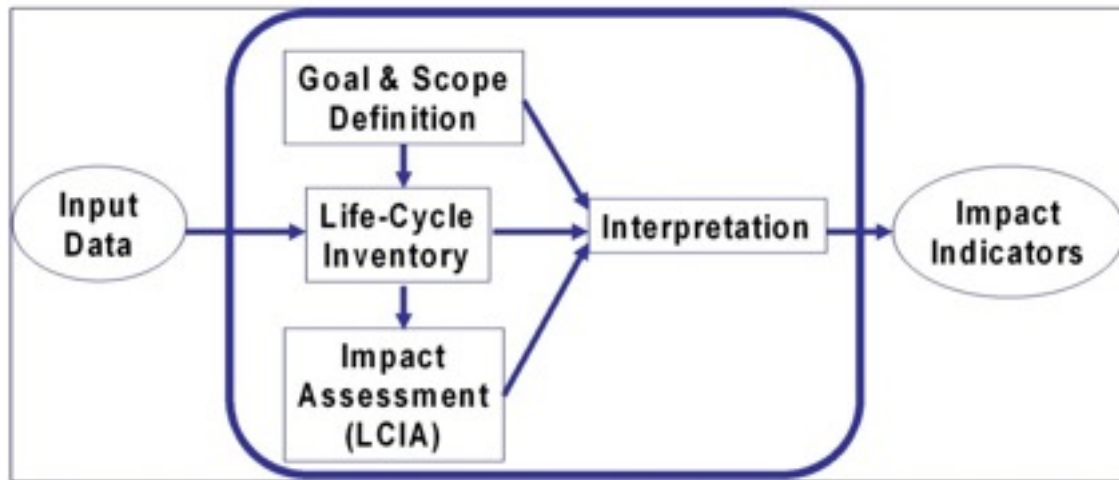


Figure 2 Life-Cycle Assessment's four interrelated steps (adapted from <http://www.epa.gov/NRMRL/lcaccess/pdfs/600r06060.pdf>)

The goal definition and scoping step describes the purpose of the study. For example, the products to be considered and system boundaries are defined at this point. The LCI is an objective, data-based process of quantifying energy and raw material inputs, and the emissions to air, water and land. The LCIA process characterizes and calculates the effects of the emissions identified in the LCI into impact categories such as global warming potential, habitat modification, acidification, or noise pollution.

Outcomes from LCAs can be used to select more “environmentally friendly” products or to improve the environmental impacts of a particular product.

3.4 Previous Studies

The wood manufacturing industry in the US obtains more than 50% of their heat energy requirements by burning wood residues created during product production (Puettmann and Wilson 2005; Puettmann et al. 2010). The primary heating sources for residential heating in the US are natural gas and electricity (EIA 2011) but firewood and wood residues can be burned to supplement or even replace these energy sources. However, these wood fuels can be inconvenient to handle and store.

Pelletization of wood residues can produce a more convenient fuel. Pellets are dry, dense, easily-handled and stable in long-term storage. Pellets can be burned directly as a heating fuel or can be an initial processing step in a bio-refinery or bio-fuel conversion process (Magelli et al. 2009). Wood pellets are an established fuel product that is growing in importance in the US and abroad, driven by rising fuel prices and demands for green energy sources. There are some published LCA studies for production of pellets (Katers and Snippen 2011, Pa et al. 2012) but none for pellets produced in the southeastern U.S. from hardwood flooring residues.

3.5 Southeast Pellet Production

Pellet fuel in the United States emerged as an alternative to oil in the 1970s after a sharp increase in oil prices. This was especially true in the Northeast where pellets offered a convenient alternative for home heating. In contrast, the development of the pellet industry in the Southeast has been

relatively recent. According to a report by the USDA on North America's Wood Pellet Sector, 2009 pellet production in the Southeast was over 600,000 tons (550,000 Mg) (Spelter and Toth, 2009). Most of the southeastern pellet mills are components of other primary wood product facilities (e.g., hardwood flooring mills). Other, unattached operations use the same waste material from separate facilities.

While there have been several policy incentives to encourage new sources of bio-energy, such as the Biomass Crop Assistance Program (BCAP), it appears that the economic downturn of 2009-2010 has impeded the expansion of the pellet industry in the Southeast. The Pellet Fuel Institute (pelletheat.org) as well as the previously mentioned USDA study lists 30 pellet manufacturers in the Southeast. Several of those facilities, however, have either temporarily halted production or entirely shut down as of the summer of 2010. Despite this recent, local downturn, there is an overall trend of significant expansion in the global production and consumption of wood pellets (Spelter and Toth, 2009)

3.6 Goal

The goal of this study was to document the life-cycle inventory (LCI) of manufacturing wood pellets based on resources from the southeastern pellet-manufacturing region. The output of this study is intended for use by researchers and practitioners as an input to the life-cycle analysis (LCA) of woody biomass materials in a cradle-to-gate analysis. This study, however, measured only the impacts associated with the production of pellets from hardwood flooring

residues. The primary data were collected by a survey of pellet manufacturers. Secondary data included electricity rates (to determine electricity consumption by individual pellet mills when electricity expense was reported) as reported by the U.S. Energy Information Administration (EIA 2009) and hardwood flooring residues production from the US LCI database (Hubbard and Bowe 2010).

3.7 Scope

This study surveyed the use of dry hardwood flooring residues for pellet production in the Southeast region of the U.S. Product transportation was beyond the scope of the study. We selected this region because it is the single largest and fastest-growing region for wood pellet production (Spelter and Toth, 2009). To conduct the survey of wood pellet manufacturers, all of the pellet mills (24 mills for the Southeast region in operation at the time of survey) were contacted and sent a LCI survey from October to December 2009. Of the mills surveyed, six (25%) responded with complete data in terms of pellet production, raw materials, electricity and fuel use. Respondents were obtained from mills in Alabama, Kentucky, Tennessee, Virginia and West Virginia. Surveyed LCI data represented 2009 production data. The survey served as the main tool for the inventory (LCI) collection (gate-to-gate). SimaPro LCA modeling software (PRé Consultants 2011) was used calculate the overall cradle-to-gate emissions associated with the pelletization process using a network of related inventories associated with the inputs for pellets. Impact indicators were calculated using the TRACI 2 v.3.03 model (US EPA 2011).

3.7.1 Wood Pellet Process Description

The manufacture of wood pellets comprises the following processes: raw material (wood waste) collection, drying, hammer-milling, pelletizing, cooling and bagging. The inputs are wood waste from wood flooring manufacturing (sawdust, trimming, scraps, etc.), energy (electricity and fuel), lubricants (corn oil, grease), and water. The output is bagged densified wood fuel pellets. Any wood residues generated during pellet production are recycled in the system. Pellets generated by the companies surveyed in this study generally meet the ‘premium’ standard of the Pellet Fuels Institute (PFI 2010).

Unit process and system boundary

The processes described in figure 3 are within the system boundary for the LCI analysis of wood pellet manufacturing (“pelletization”). The dotted and solid lines cover pelletization and cumulative emissions, respectively. The pelletization system boundary covered the cradle-to-gate emissions including emissions generated for material and energy produced off-site such as grid electricity that is used on-site but excludes cradle-to-gate emissions for wood residue production. Life-cycle data for wood residue production were provided on a mass allocation basis. About 50% of wood leaving the wood flooring manufacturing process was wood residue therefore the wood residue carries 50% of the burden from the wood flooring manufacturing process. Cumulative emissions (the solid line) cover the cradle-to-gate emissions generated for material and energy produced for both wood residue and pelletization production.

The functional unit was 1 ton (2000lbs = 907kg = 0.907 Mg) of wood fuel pellets, which is the standard unit in commerce (pallets are loaded with 50 40-pound bags). The following describes each of the manufacturing processes.

1. Raw material (waste) collection. Raw material is collected on-site from a connected but separate wood processing facility such as a hardwood flooring mill. Approximately half of the hardwood lumber raw material is converted to flooring; the remainder (sawdust, planer shavings, trim blocks and edging strips) is available for the pellet process. The raw material is stored in a dry facility on-site.
2. Drying. Raw materials, when taken from green feedstock (i.e. roundwood), must be uniformly dried to a low moisture content (9 – 11% on an oven-dry basis). The mills surveyed for this study all use waste residue from adjoining facilities, which already has a low moisture content level; however, additional drying is sometimes used even for dry residues. One facility in this study did use a gas boiler, which significantly impacted their energy input. Another facility used wood waste (sawdust) to dry 80% of their raw material. Weighted averages of both of these facilities' inputs were used in the inventory analysis.
3. Hammer mill. Once the material is collected, it is broken down into small, uniform particles (~2 mm) using a hammer mill. The hammer mill is operated by electric motors.

4. Pelletizer. Pellets (~6mm diameter and 25mm long) are extruded using machinery that is similar to the equipment used to form feed pellets for the agriculture industry. Pelletizers use large electric motors to extrude the pellets through steel dies. High pressure (~300 MPa) and temperatures (~90°C) soften lignin and binds the wood particles together to make uniform and consistent pellets. While no adhesives are required for this process, small amounts of lubricants and water are sometimes added to improve processing.
5. Cooling. The pellets are hot when they emerge from the pelletizer. They are stored in a hopper and allowed to cool before bagging.
6. Bagging. Finished pellets are bagged, usually in small, semi-automated bagging lines that are powered by electricity. Pellets are usually fed by conveyor to a bagging station where the pellets are fed into 40 lb (18.14 kg) plastic bags.

Because we were unable to collect data for each component of the pelletization process, this LCI does not separate inputs and outputs by unit processes; instead, data were collected on the processing of wood pellets as a whole system from gate (wood residue) to gate (bagged pellet).

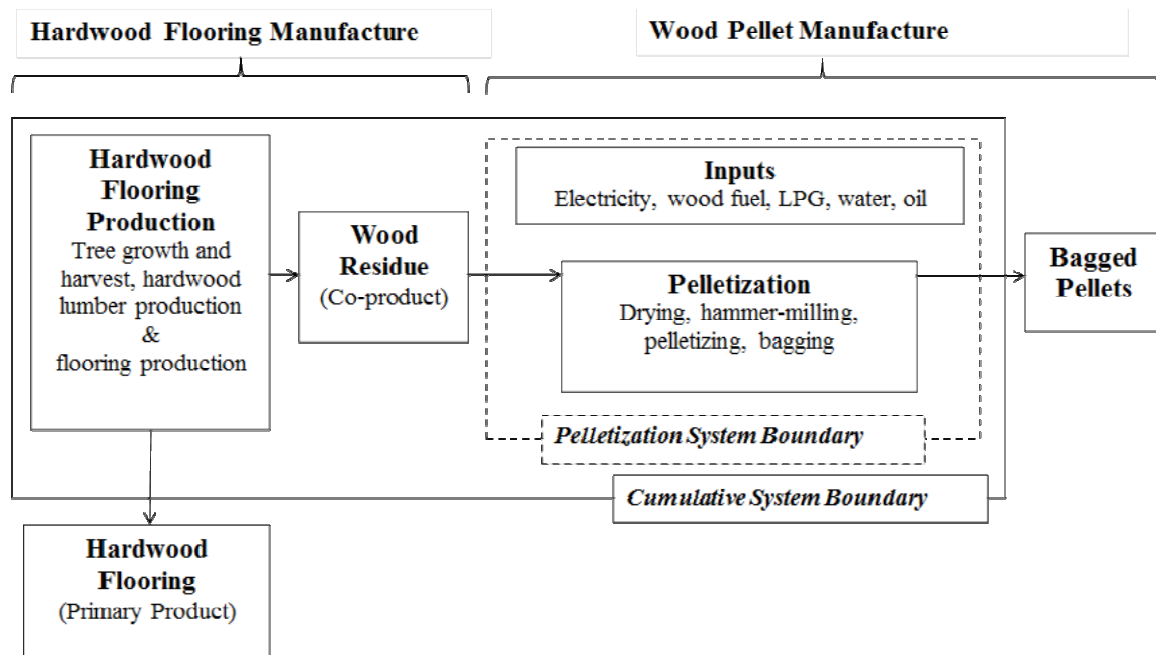


Figure 3 Components of the wood pelletization process.

The system boundary covering pelletization is represented by the dashed line and the solid line represents the cumulative processes. Fines produced during pelletization and bagging are returned to the process. Most mills surveyed did no additional drying of the raw materials before pelletization. The hardwood flooring manufacturing flow was adapted from Hubbard and Bowe (2010).

3.7.2 Assumptions

The data collection, analysis, and assumptions followed the protocol defined in "Consortium for Research on Renewable Industrial Materials (CORRIM)—Research Guidelines for Life-cycle Inventories" (CORRIM 2010).

Additional conditions include:

- All data from the survey were weight averaged for the six plants based on their inputs, outputs, and production for one year (2009). Missing data were not included in the weighted averages.

- The electricity consumption (the largest input of this manufacturing process) is expressed as kWh per ton of pellets using electricity data taken from the US LCI Database (NREL 2011). Most pellet manufacturers reported electricity bills that allowed us to calculate the energy (kWh) based on their production rate. One mill reported actual kWh usage.
- Only two mills reported values for oil and grease as inputs. These amounts were calculated per ton of wood pellets. The weighted average for these two reporting manufacturers assumed that the other manufacturers used similar amounts of oil and grease as lubricants.
- Only one mill reported a value for liquid petroleum gas (LPG), 1.37 gallons per ton of wood pellets (5.71 L/Mg). This mill used LPG for further drying before pelletization. This input was weighted according to production percentages.
- Two mills reported values and gave samples of bags used for the finished pellets. It was assumed that these bags were representative of bags used at all of the mills.
- One mill reported using 80% green wood feedstock. They used heat from burning wood residues to dry their feedstock and this wood input was weighted according to production percentages and included.

Environmental impacts associated with the pellet mill equipment, and any replacement parts, were not included.

Data quality and standard compliance

The size of the production facilities from the survey ranged from 6,000 to 125,000 tons (5,440 – 113,000 Mg) of wood pellets annually. Most of these facilities were co-located with hardwood floor manufacturers. Pellet facilities ranged widely in operation times and employees. Some facilities were 24 hour a day operations, while many of them were run for five days a week at eight hours a day.

The total production of responding pellet mills was 335,074 tons (303,912 Mg) of pellets a year. The only available production data estimated production of the entire Southeast region in 2008 was 652,561 tons (591,873 Mg; USDA, 2009), which suggests that our survey captured production information from mills that produce about half of the total regional production.

The reported data are consistent with other pelletization energy consumption values reported in other studies (Thek and Obernberger 2004, Patzek and Pimentel 2005, Swigon and Longaur 2005, EUBIA 2007, Uasuf and Becker 2011). The procedures and report of this study follow the standards in ISO 14040 (ISO 2006). The procedures and report also follows the CORRIM research guidelines for life-cycle inventories (CORRIM 2010).

3.9 Material flows

The most significant inputs for pellet operations are wood residues and electricity. The surveyed manufacturers reported no co-generation of electricity. Other fuels used are primarily for rolling stock (i.e. forklifts) and include diesel

fuel and LPG. This machinery was usually shared between the pelletization plant and other components of the hardwood flooring operation. The survey respondents were unable to report a fuel usage for these machines specifically for the pelletization operation. Given the limited requirements for these machines in the pellet making process, these inputs were assumed to be insignificant. Other material inputs used in the manufacture of wood pellets are plastic bagging, water, oil, and grease. Water is used to adjust the moisture content during pelletizing. Some oil and grease are used for lubrication in the pelletizing process.

The process of pelletizing wood waste changes only the density of the wood residue raw material. Therefore, it takes one ton of wood residues to produce one ton of wood pellets. However, other inputs (such as energy) go into the process (Table 5).

Table 3 Inputs to the pelletization process for one ton of wood pellets in the Southeast

INPUTS		
<i>Materials</i>	<i>Units</i>	<i>Quantity</i>
Wood residues	lbs	2000
Polyethylene (50 bags)	lbs	11.02
Corn oil (lubricant)	gal	0.33
<i>Water input</i>		
Ground water	gal	5.74
<i>Energy</i>		
Electricity	kWh	132.12
Liquefied petroleum gas	gal	0.02
Wood residues to boiler	lbs	65.94

Process output

Wood pelletization primarily has energy and wood residue inputs and only one output—wood pellets. Because air, water and solid waste emissions are minimal, the majority of emissions (Table 6) are those associated with pre-gate actions (hardwood flooring manufacture and electricity production).

Emission and waste characterization

Wood pelletization does not create a solid waste stream.⁵ All wood residues are recycled in the pelletization process and air-borne particulate emissions (dust) are assumed to be insignificant. The cumulative life-cycle emissions and wastes associated with wood pelletization are pre-gate (i.e. those associated with wood flooring production and electricity production). There are no emission control measures employed during pelletization.

3.10 Life-cycle Inventory

Tables 6, 7 and 8 list the emissions to air, water, and soil for wood residues production (cradle to gate), for the pelletization process (gate to gate) and for these two processes combined (cumulative). The data collected by our survey for the pelletization process are shown below as “pelletization” impacts. The cumulative emissions include those associated with the growth, harvest and transportation of logs and the production of the hardwood flooring that results in the creation of wood residue, and the emissions associated with the production of the electricity that is used during pelletization. Separation of the wood residue production, pelletization and cumulative impacts in this way enables analysis of the relative importance of the pelletization process. Pelletization-associated fossil CO₂ emission of 251 lb/ton (125 kg/Mg) includes emissions from generation of the electricity used to run the pellet equipment and burning LPG to dry the wood

⁵ Except for wood ash in cases where wood residues are dried using a wood-fired boiler. As noted in the *Assumptions*, there was one producer that dried using a wood-fired boiler but they were unable to report an ash value.

residue. In addition, woody biomass is burned on-site for drying the wood residue as shown by a biomass CO₂ value of 144 lb/ton (72 kg/Mg). Most of the fossil and biomass CO₂ emissions are associated with the hardwood flooring residues production.

Table 4 Emissions to air associated with the production of one ton of bagged wood pellets from hardwood flooring residues

	Wood residues production (cradle to gate)		Pelletization		Cumulative (wood residues production and pelletization)	
Substance	kg	lbs	kg	lbs	kg	lbs
CO ₂ (fossil)	203	448	114	251	317	699
CO ₂ (biomass)	457	1008	65	143	522	1151
Acetaldehyde	0.002	0.004	0.000	0.000	0.002	0.004
Acrolein	0.009	0.020	0.001	0.002	0.010	0.02
Formaldehyde	0.01	0.02	0.109	0.240	0.119	0.262
Phenol	0.000	0.000	0.000	0.000	0.000	0.000
NO _x	1.67	3.68	0.41	0.90	2.08	4.58
SO ₂	0.96	2.12	0.85	1.87	1.81	3.99
SO _x	0.156	0.344	0.043	0.095	0.199	0.439
Methane	0.485	1.069	0.329	0.725	0.814	1.794
Particulates (unspecified)	1.44	3.17	0.12	0.26	1.56	3.44
VOC	1.66	3.66	0.06	0.13	1.72	3.79

Table 5 Emissions to water associated with the production of one ton of bagged wood pellets from hardwood flooring residues

	Wood residues production (cradle to gate)		Pelletization		Cumulative (wood residues production and pelletization)	
Substance	kg	lbs	kg	lbs	kg	lbs
Biological oxygen demand (BOD)	4.56	10.05	0.64	1.41	5.20	11.46
Suspended solids	0.296	0.652	0.081	0.178	0.377	0.831
Chemical oxygen demand (COD)	0.053	0.117	0.021	0.046	0.074	0.163
Chloride	5.93	13.07	2.15	4.74	8.08	17.81

Table 6 Emissions to soil associated with the production of one ton of bagged wood pellets from hardwood flooring residues

	Wood residues production (cradle to gate)		Pelletization		Cumulative (wood residues production and pelletization)	
Substance	kg	lbs	kg	lbs	kg	lbs
Wood ash	0	0	0.21	0.46	0.21	0.46

3.11 Impact Assessment

Life-cycle impact assessments (LCIA) were performed using the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI 2) (Bare et al. 2003). TRACI is a midpoint oriented LCIA methodology developed by the U.S. Environmental Protection Agency specifically for the U.S. using input parameters consistent with U.S. locations. The environmental mid-

point impact categories of global warming potential (kgCO₂-eq), acidification potential (H⁺ moles-eq), respiratory effects (PM 2.5-eq), eutrophication potential (kg N-eq), and smog potential (kg NO_x-eq) were examined.

The various impact categories for the production of wood pellets, showing each input's relative contribution, are shown in Figure 4. The largest impact for each category is carried over from the wood residue material (i.e. tree growth, wood harvest, transportation, wood flooring manufacture). However, the additional input of electricity for pelletization has a significant impact on most categories. The plastic bag used to store the pellets also has a noticeable impact in some categories, e.g. respiratory effects. Other inputs used in the pellet-making process such as the oil for lubrication had insignificant impacts.

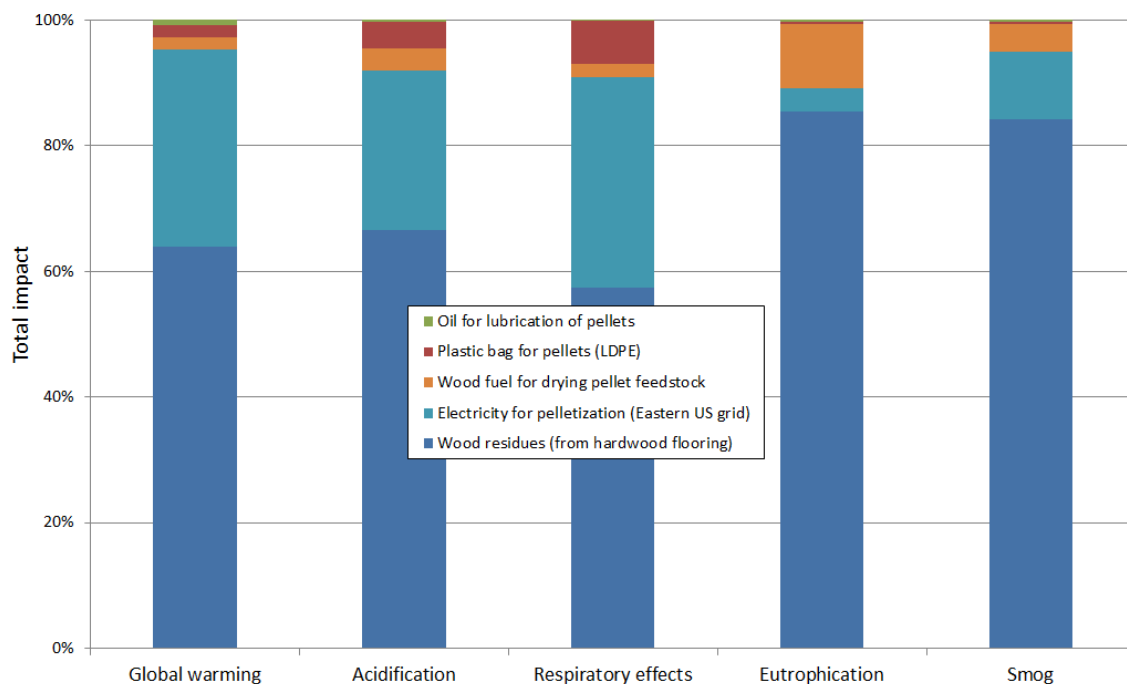


Figure 4 Impact categories showing relative contribution of the inputs

Wood pellets are a potential source of convenient renewable biomass energy but some non-renewable energy (i.e. electricity derived from coal, etc.) is required to make the wood residues, and to transform the residues into the more convenient pellet fuel. Figure 5 depicts the relationship between total potential biomass energy in the pellets and the associated cradle-to-gate fossil fuel emissions related to producing wood residues and manufacturing pellets. Wood pellets can provide a net benefit in terms of providing biomass energy, but their embodied fossil energy is significant. Wood pellets require up to 5.5 million Btu (MMBtu), or 5.8 megajoules (MJ), of fossil energy to produce 16.4 MMBtu (17.3 MJ) of bio-energy for a net balance of 10.9 MMBtu per ton (12.7 MJ/Mg).

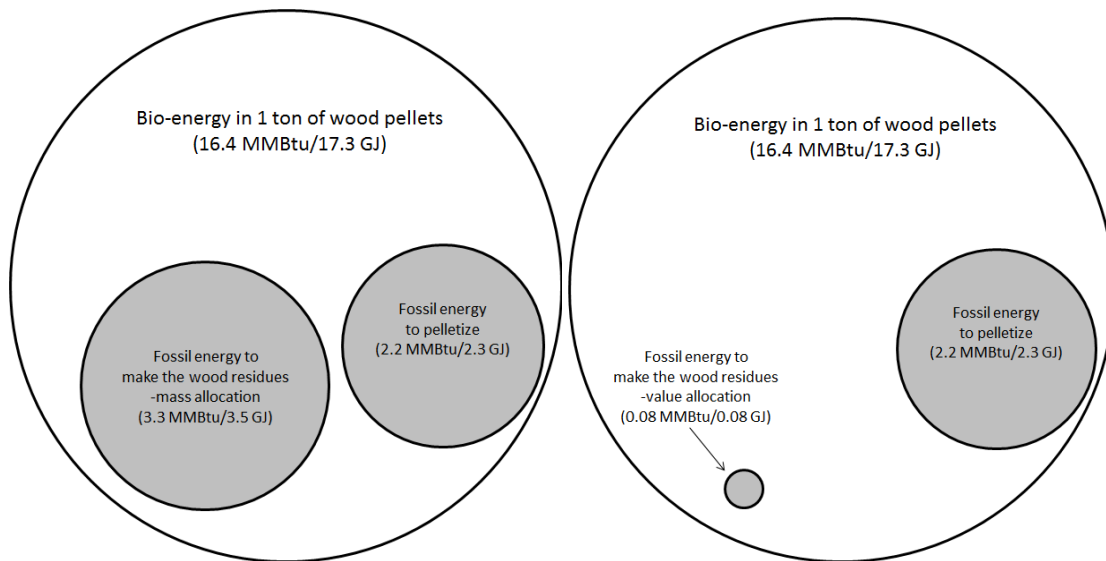


Figure 5 Potential and embodied energy in one ton of pellet fuel. Burdens are assigned to the wood residues co-product are allocated by mass (left) or by value (right) relative to the primary wood flooring product.

Wood processing residues are generated as a co-product from manufacturing hardwood flooring. Because the residues' impacts are allocated *by mass* (a 50%:50% split) from the production of hardwood flooring, pellets are assumed to carry significant environmental impacts (see Figure 4, left). A change in allocation procedure for wood flooring manufacturing would affect the conclusions considerably (Kim et al. 2009, Luo et al. 2009), because wood residues are of low value compared with the primary product (i.e. hardwood flooring). The total cradle-to-gate cumulative allocated energy (i.e. fossil- and bio-energy) required to make a wood pellet is 11.5 MMBtu per ton (13.4 MJ/Mg; based on mass-based allocation of embodied energy to the wood residues produced during hardwood flooring manufacture). If value-based allocation is used, the total embodied energy (fossil- and bio-energy) for a ton of wood pellets is reduced to 2.6 MMBtu (3.0 MJ/Mg). Biomass energy (i.e. wood combustion energy) makes up about 53% and 12% of the total embodied energy in mass- and value-based allocation scenarios, respectively.

For wood flooring manufacturing, if allocation were done by economic value instead of mass, the burdens assigned to the (low-value) wood residues would be reduced. For example, if we assume that wood flooring has a wholesale value of \$2 per square foot (\$1,600 per ton; \$1764 per Mg) and that wood residues have a value of \$20 per ton (\$22 per Mg; at the mill gate), then the allocation of burdens would be 98.8% to the flooring product and 1.2% to the residues. In that scenario, the fossil energy associated with producing the

residues would be reduced from 3.3 to 0.08 MMBtu (3.4 to 0.08 GJ; Figure 5, right). If the wood flooring residues were assumed to have no environmental impacts associated with them (i.e. the burdens were allocated entirely to the flooring), then only the *additional* inputs required to convert the hardwood flooring residues to pellets would be considered and only the pelletization-specific inputs and emissions described above would apply to the pellet product. Allocating all the burdens to the wood flooring would be consistent with the premise that wood flooring manufacturers are in the business to make flooring not wood residue. However, because there is a (relatively small) economic value in wood residues, economic allocation may be the most appropriate method (Jungmeier et al. 2002, FPInnovations 2011).

Because the amount of non-renewable energy used to produce pellets is less than the potential bio-energy they contain (Figure 5), the global warming potential (GWP) of pellet fuel is much less than fossil fuels such as natural gas (Figure 6). Allocation of the burdens (i.e. fossil energy inputs) from wood residues production is again an important variable in the analysis. If embodied fossil energy inputs are allocated to the hardwood flooring residues by mass, then the GWP of pellets is roughly one-third that of gas; however if the residues are considered to be a low-value co-product product, then the GWP of pellet fuel becomes negative. If the wood flooring residues are simply considered a waste, and are assumed to carry no embodied fossil energy, the GWP calculation becomes even more favorable (data not shown); however, the additional

apparent benefit is minor given the assumed low monetary value of the wood residues (1.2% of the total value).

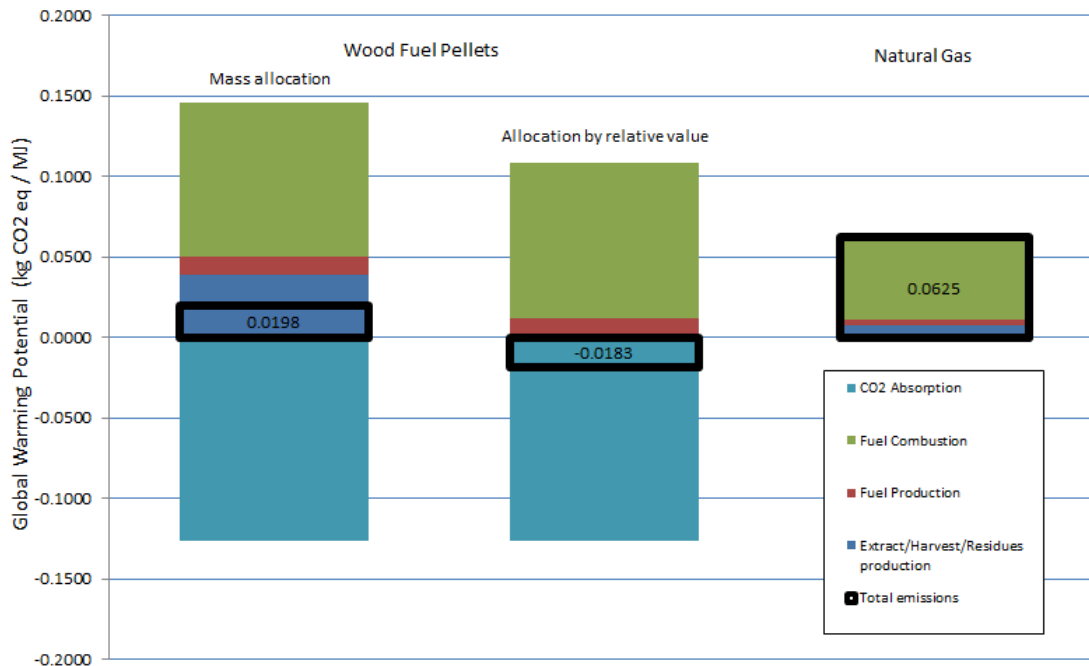


Figure 6 Global warming potential of wood pellets and natural gas.

Burdens assigned to the wood residues co-product are allocated by mass (left) or by value (middle) relative to the primary wood flooring product. Transportation of the fuels to the combustion site and possible differences in combustion efficiency are not considered.

3.12 Summary

This study presents a life-cycle inventory and life-cycle impact assessment for the production of wood fuel pellets in the Southeast region of the United States. Operating mills were surveyed to collect data for a gate-to-gate life-cycle inventory. A cradle-to-gate inventory was developed using an existing life-cycle data for wood residues, electricity and the other inputs. The primary inputs for

manufacturing wood fuel pellets are wood residues and electricity. In the Southeast region, an average of 132 kWh of electricity was reported just for the pelletization of one ton of wood residues.

Life-cycle impact assessment allows for the interpretation of several impact categories such as global warming potential (weighted net emissions of GHG), acidification, carcinogenics, respiratory effects, and eutrophication. Applying the mass allocation procedure for wood flooring manufacturing, the production of wood residues from hardwood lumber manufacture contributes the most to the total environmental impacts of wood pellet products. The electricity required during pelletization also contributes significantly, e.g. 30% of the global warming potential and the total respiratory effects are associated with this input. The plastic bag used for bagging pellets represents a smaller, but still significant, impact in some categories.

Comparison of the biomass energy in pellets with the significant fossil energy inputs required for their production shows that wood pellets provide a net renewable energy source. Net energy available in wood pellets is 10.9 MMBtu (11.5 GJ) per ton or more. Analysis of the energy balance and environmental impacts of pellets is greatly affected by the allocation method used. The appropriate allocation method when the residual co-product is of lower value than the primary product, as is the case for hardwood flooring residues, would be a value allocation by which the primary product carries almost the full burden up until the waste is used as a feedstock for the production of pellets. The fossil

emission reductions when combusting pellets compared to natural gas varies from 129% reduction when the flooring burdens are allocated to the pellets based on their relative value to 68% when mass allocation is assumed.

CHAPTER 4 - CRADLE-TO-GATE LIFE-CYCLE INVENTORY OF SWITCHGRASS FUEL PELLETS IN THE SOUTHEASTERN UNITED STATES

3.1 Abstract

This study presents a life-cycle inventory (LCI) data for switchgrass fuel pellets potentially manufactured in the US southeast. Since there are no current manufacturers of switchgrass, inventory data will be based on field trials of the growth and harvest of switchgrass and from a separate study of wood pelletization. Growth and harvest data were collected by survey from switchgrass farmers in east Tennessee and represent growth and harvest data for years 2008, 2009, and 2010. Inputs and outputs regarding pelletization were taken from a separate report on wood pellet manufacturing in the US southeast. The growth and harvest process was combined with the pelletization process and an impact assessment was conducted using the TRACI model. The potential bi-energy and embodied non-renewable energy in one ton (the functional unit of this study) of switchgrass pellets was also calculated. While switchgrass requires a significant amount of energy and inputs inside the growth and harvest process, the majority of the environmental burdens are associated with pelletizing the raw material.

3.2 Introduction

There are a number of factors motivating the development of bio-fuels and bio-products: high petroleum prices, a desire for energy independence, the need for rural economic diversification and concern about the environmental impacts of using fossil carbon sources. With regard to the last point, intuition suggests that products and fuels made from plants inherently have environmental advantages: they are renewable and solar-powered, and their use is carbon-neutral with respect to greenhouse gas concentrations and global climate change. However, there is growing debate about these potential environmental benefits and more attention is being paid to the amount of fossil carbon resources consumed in the production and processing of bio-energy and the potential tradeoffs (e.g. between food and fuel) involved. While the environmental advantages of bio-based resources remain important, they can no longer be assumed – they must be demonstrated, using generally accepted methods. Life-cycle assessment (LCA) is the standard method for evaluating the environmental impacts of processes and products. The basis for LCA is the life-cycle inventory (LCI), an accounting of all of the inputs and outputs related to the product or process being evaluated (ISO 2006).

Switchgrass (*Panicum virgatum* L.) is a perennial tall-grass indigenous to Central and North America. In the Southeast, this perennial crop can grow up to eight feet tall and has a peak growing season from May through September. Switchgrass and other crops are being developed as new sources for bio-energy

and bio-products. Because these crops are harvested seasonally and are bulky, pelletization may be necessary as a primary processing step. Pellets are dry, dense, easily handled and stable in long-term storage. Pellets are burned directly for fuel or can be an initial processing step in a biorefinery or bio-fuel conversion process. Wood pellets are an established fuel product that is growing in importance in the US and abroad, driven by rising fuel prices and demands for green energy sources. Switchgrass pellets have the potential to join wood pellets in this growing market.

Some LCA data on switchgrass pellet production have been published for Canadian and European contexts (Jannasch et al. 2001; Smeets et al. 2009; Cherubini and Jungmeier 2010). This study focuses on the southeastern United States. The data are intended for analyses of pelletized biofuels and for related products (e.g. when switchgrass or pellets are a component of a biorefinery).

3.3 Goal

The goal is to develop an inventory of the inputs and outputs associated with the production of switchgrass pellets in the southeastern United States. Results can be used in the assessment and interpretation phases to identify major sources of environmental impact and to compare the environmental impact of switchgrass pellets with other energy sources. The output of this study is intended for use by researchers and practitioners as an input to the life-cycle analysis (LCA) of biomass materials in a cradle-to-gate analysis. Because there is currently no commercial production of switchgrass pellets, this life-cycle

inventory will be based on data from field trials of the growth and harvest of switchgrass and from a separate study of the wood pelletization process (Reed et al. 2012). The primary data for the growth and harvest of switchgrass were collected by a survey of participating farmers.

3.4 Scope

This is a cradle-to-gate life-cycle analysis of switchgrass pellets and includes data from the growth and harvest of switchgrass plantations that have been established in east Tennessee as part of the University of Tennessee Biofuels Initiative (UTBI).⁶ Initiated by a \$70.5 million dollar state investment, this initiative has been charged with developing a cellulosic biofuels industry in Tennessee. Part of this approach is hiring farmers to grow switchgrass as well as the creation of a pilot biorefinery located in Vonore, TN. Raw material transportation values to a pelletization plant are assumed. A pelletization process is based on data from the pelletization of wood pellets. This study does not consider the impacts of the ultimate use of the pellets (i.e. “gate-to-grave”) including pellet transportation and combustion or other processing. Growth and harvest data were collected by survey sent to switchgrass farmers. The farms ranged from first-year to mature, third-year stands. Because inputs (primarily fertilizer treatments) decrease after stand establishment, and yields increase, the data were averaged and weighted over a ten-year period (the assumed stand rotation).

⁶ http://www.generaenergy.net/faqs/ut_biofuels_initiative.aspx

Because no commercial switchgrass pellet mill data are available, data from a survey of wood pelletization mills in the US southeast was used (Reed et al. submitted).

3.4.1 Unit process and system boundary

The processes described in Figure 1 are the basic flows within the system boundary for the cradle-to-gate LCI analysis of a switchgrass pellet-manufacturing model. The functional unit was 1 ton (2000lbs = 907kg = 0.907tonne) of switchgrass pellets. The following describes each of the manufacturing processes:

1. *Growth and Harvest.* Switchgrass is grown as a yearly perennial crop. In the southeast growth and harvesting usually takes place during late fall to mid fall. After harvesting it is baled and loaded onto trucks for transport.
2. *Transportation.* After baling, switchgrass is loaded onto tractor-trailer trucks and transported to pellet mill for processing.
3. *Storage.* In a projected model of a switchgrass pelleting facility, raw material would be transported by truck to the pellet mill. The raw material would then be stored in a dry facility on-site. Inputs for raw material collection include diesel fuel and/or liquid propane gas for transportation and/or handling.

4. *Drying.* Since there are no facilities that currently pelletize switchgrass, drying was estimated to require 0.62 million BTUs per ton of switchgrass to go from 20% moisture content to 10% moisture content.
5. *Pelletization.* Because we were unable to collect data for each component of the pelletization process, this LCI treats pelletization as a single process. In reality, the pelletization process includes, size reduction, pelletization and cooling processes. *Size reduction.* Once the material is collected, it is broken down into small, uniform particles (~2 mm) using a hammer mill. The hammer mill is operated by electric motors. Pellets (~6mm diameter and 25mm long) are extruded using machinery that is similar to the equipment used to form feed pellets for the agriculture industry. Pelletizers use large electric motors to extrude the pellets through steel dies. High pressure (~300 Mpa) and temperatures (~90°C) soften lignin and binds the switchgrass particles together to make uniform and consistent pellets. While no adhesives are required for this process, small amounts of lubricants and water are sometimes added to improve processing.
6. *Cooling.* The pellets are hot when they emerge from the pelletizer. They are stored in a hopper and allowed to cool under ambient conditions before further handling, transportation and storage.

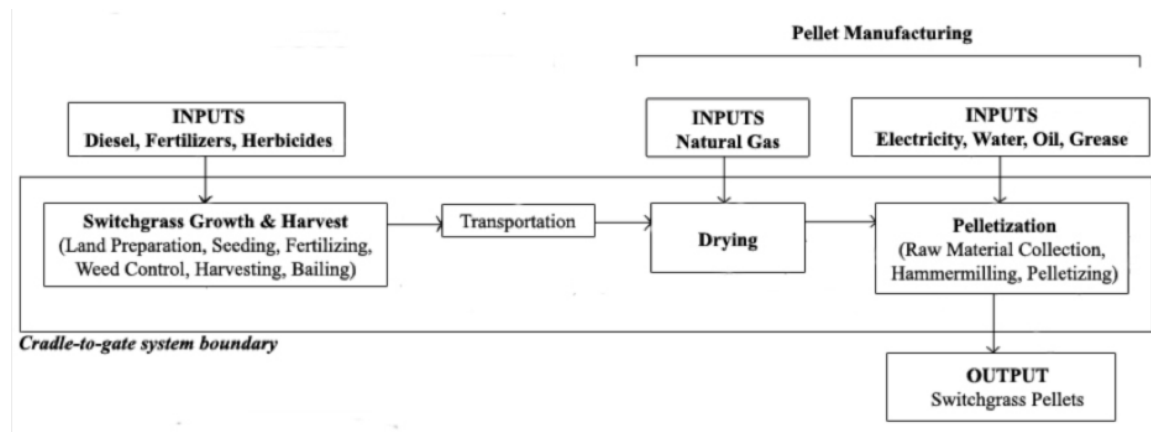


Figure 7 System description for the production of switchgrass pellets

3.4.2 Assumptions

The data collection, analysis, and assumptions followed the protocol defined in “Consortium for Research on Renewable Industrial Materials (CORRIM)—Research Guidelines for Life-cycle Inventories” (CORRIM 2010).

Additional conditions include:

- All data from the switchgrass farmer survey were weight averaged over a period of 10 years to account for input and yield variations over the life of the stands.
- Transportation was based on an assumption of 50 mile average distance by truck with a 20-ton load.
- Switchgrass typically dries on the field to 20%MC or less before being baled and shipped to the plant for drying (Rinehart 2006). Drying inputs (natural gas) of the switchgrass prior to pelletization was estimated by an

expert in the area of biomass processing (Gary Follmer, M-E-C Company, 2012, pers. comm., March 15) as 621,000 BTUs per ton to dry switchgrass to 10% moisture content, requiring 758 cubic feet of natural gas combusted at 80% efficiency (FPL 2004).

- The pelletization process for dry switchgrass was assumed to be the same as for pelletization of wood processing residues, as reported by Reed et al. (submitted).

3.4.3 Data quality and standard compliance

Data was collected by survey results from 75 switchgrass farmers contracted by the University of Tennessee. This survey was sent out in 2009 and represents growth and harvest data for 2008, 2009, and 2010. Usable responses were collected from twelve farmers with data on 376 acres. The survey responses for wood pellet manufacturers represented 2009 production data from approximately 25% of the total number of operating mills in the Southeast region. The total production of responding pellet mills were 335,074 tons of pellets a year. The only available production data estimated production of the entire Southeast region in 2008 was 652,561 tons (Spelter and Toth 2009).

The switchgrass yield data collected in our survey were consistent with published data (Smeets et al. 2009) but inputs (e.g. Fertilizer) were lower. The procedures and report of this study follow the standards in ISO 14040 (ISO 2006a) and 14041 (ISO 2006b). The procedures and report also follows the CORRIM research guidelines for life-cycle inventories (CORRIM 2006). This

review was to assure inventory guidelines were followed and LCA software (SimaPro) methods were appropriate (Pre Consultants 2012).

3.5 Material Flows

Survey responses from the farmers covered stands that were up to three years old. It was assumed that inputs and yields were constant from year 3 until year 10, the assumed stand rotation (Rinehart 2012) and the inputs per ton were calculated based on an average yield of 6.2 tons per acre per year. There are several inputs for the growth and harvest of switchgrass, the most significant of which is nitrogen fertilizer (Table 1). Other inputs include diesel, phosphorous fertilizer, pesticides, herbicides and surfactant. The most significant input for pellet-making operations in the Southeast is electricity. Other fuels used for equipment (i.e. tractors, trucks, forklifts) include diesel fuel, and liquid petroleum gas (LPG). Other raw material inputs used in the manufacture of wood pellets are water, oil, and grease. Water is used to adjust the moisture content and oil and grease are used for lubrication during the pelletizing process. The process of pelletizing switchgrass changes only the density of the biomass raw material. Therefore, it was assumed that one ton of switchgrass is required to produce one ton of pellets. Jannasch, Quan and Samson (2001) speculated that 95% yield might be more realistic.

Table 7 Cradle-to-gate inputs for one ton of switchgrass pellets in the US Southeast averaged over a 10-year stand rotation.

<i>Materials</i>	<i>Units</i>	<i>Quantity</i>
<i>Switchgrass Production</i>		
Diesel (tractor use)	gal	0.96
Nitrogen (fertilizer)	lbs	9.54
Phosphorous (fertilizer)	lbs	0.98
2, 4-D (pesticide)	lbs	0.09
Glyphosate (herbicide)	lbs	0.10
Surfactant	lbs	0.02
<i>Transportation</i>		
Diesel	tmi	50
<i>Drying</i>		
Natural Gas	cuft	728
<i>Pellet Manufacturing</i>		
Corn Oil (lubricant)	gal	0.33
Ground Water	gal	5.73
Electricity	kWh	132.12

3.5.1 Process output

Pelletization primarily has energy and switchgrass inputs and only one output—switchgrass pellets. Because on-site air, water and solid waste emissions are insignificant, the emission data here (Table 2) are those associated with cradle-through-switchgrass transportation as well as those associated with the production of the other pelletization inputs (electricity and corn oil).

3.5.2 Electricity usage

The weight-averaged electrical usage reported per functional unit (1 ton) of wood pellets was 132 kWh (Reed et al, submitted). This is consistent with other publications on wood pellets (Uasuf and Becker 2011; Pa et al. 2012) but significantly more than values estimated in some publications related to switchgrass pelletization (Smeets et al. 2009). We chose to use the wood-pellet value because it is based on surveyed commercial production, albeit for a different material. Because electricity is the primary energy for pelletization, the source of the fuel used for electricity generation is important in determining the environmental impacts of pellet making. In the United States, the primary fuel sources for electricity are coal, nuclear energy and natural gas (US EIA 2012).

3.5.3 Emission and waste characterization

Pelletization does not create a solid waste stream. All residues are recycled in the pelletization process and air-borne particulate emissions (dust) are assumed to be insignificant. The cumulative life-cycle emissions and wastes associated with pelletization are pre-gate (i.e. those associated with switchgrass and electricity production). There are no emission control measures employed during pelletization.

3.6 Life-cycle Inventory

This cradle-to-gate LCI includes inputs and outputs for switchgrass stand establishment, averaged over a 10- year rotation, crop transportation, drying and

pelletization, expressed on a per-ton-of-pellets basis. Tables 2, 3 and 4 list the emissions to air and water. There are no emissions to soil in this inventory.

Table 8 Emissions to air for one ton of switchgrass pellets, cradle-to-gate.

	Switchgrass Growth and Harvest		Pelletization		Cumulative (growth and harvest and pelletization)	
Substance	kg	lbs	kg	lbs	kg	lbs
CO ₂ (fossil)	5.39	11.88	153.61	338.65	159	350.53
CO ₂ (biomass)	.073	0.16	2.04	4.49	2.11	4.65
NO _x	0.023	0.1	0.379	0.83	0.402	0.88
SO ₂	0.206	0.5	1.074	2.36	1.28	2.82
SO _x	0.009	0.02	0.034	0.07	0.0435	0.096
Methane	0.106	0.23	0.438	0.96	0.544	1.19
Particulates (unspecified)	0.004	0.008	0.072	0.16	0.076	0.16
VOC	0.006	0.013	0.022	0.05	0.0279	0.06

Table 9 Emissions to water for one ton of switchgrass pellets, cradle-to-gate.

	Switchgrass Growth and Harvest		Pelletization		Cumulative (growth and harvest and pelletization)	
Substance	kg	lbs	kg	lbs	kg	lbs
Biological Oxygen Demand (BOD)	0.012	0.026	0.019	0.042	0.0312	0.068
Suspended Solids	0.056	0.12	0.143	0.31	0.161	0.355
Chemical Oxygen Demand (COD)	0.018	0.04	0.034	0.07	0.052	0.115
Chloride	1.64	3.61	3.69	8.13	5.33	11.75

3.7 Impact assessment

Pelletization converts a potential fuel or raw material for products into a more convenient form, thus it is interesting to analyze the additional environmental impacts that are associated with this convenience.

Life-cycle impact assessments (LCIA) were performed using the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) (Bare 2012). TRACI is a midpoint-oriented methodology developed by the U.S. Environmental Protection Agency specifically for the United States. The impact categories of global warming potential (kgCO₂-eq), acidification potential (H⁺ moles-eq), carcinogens (kg benzene-eq), non-carcinogens (kg toluene-eq), respiratory effects (PM 2.5-eq), eutrophication potential (kg N-eq), ozone depletion (kg CFC-11-eq), ecotoxicity (2,4-D-eq), and smog potential (kg NO_x-eq) were examined.

Figure 2 lists various impact categories, showing each input's relative contribution. The production of electricity used in the pellet manufacturing process accounts for the largest impact for five of the categories (global warming, acidification, carcinogenics, respiratory effects, and smog). However, impacts associated with the growth and harvest of switchgrass make up the largest impact for four of the categories (non-carcinogenics, eutrophication, ozone depletion, and ecotoxicity). While the impacts associated with drying the feedstock (natural gas) relative to the other processes are significantly less in

every category, these impacts are clearly visible in global warming, acidification, non-carcinogenics, respiratory effects, and ecotoxicity categories.

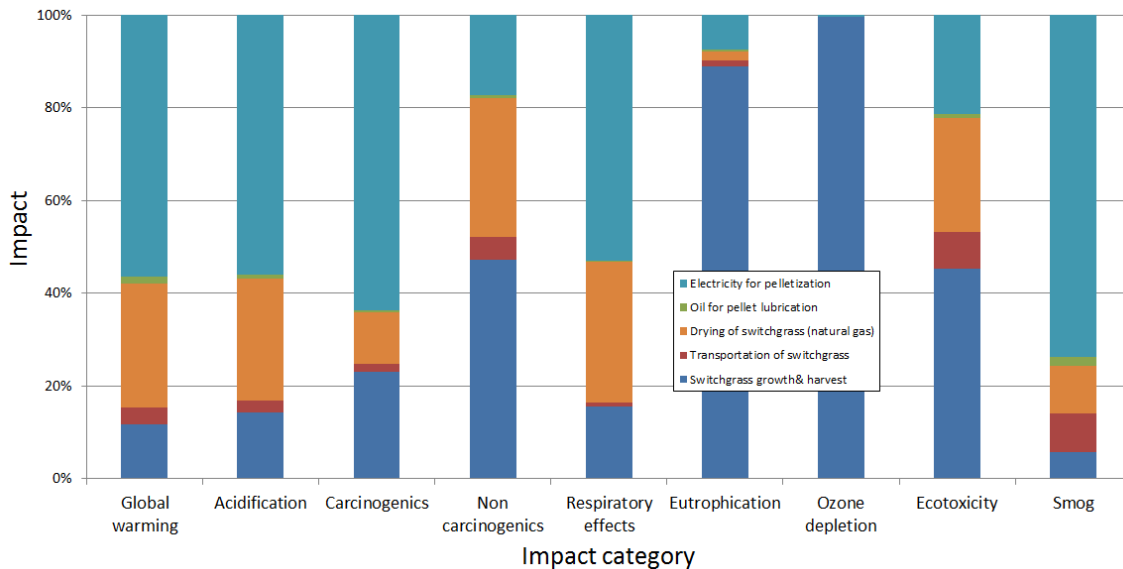


Figure 8 Impact categories showing relative contribution of the inputs

Biomass energy sources are sometimes considered to be ‘carbon-neutral’ (IPCC 2006; Tilman et al. 2006) for accounting purposes because the carbon dioxide (CO₂) released during energy production is offset by CO₂ adsorption during photosynthesis (e.g. Bare 2002). However, some fossil energy inputs are required for the production of most bio-fuels. The fossil energy required for the production of switchgrass pellets was calculated from the inventory data tabulated by Sima-Pro and weighted for their energy content (higher heat value). This analysis revealed that switchgrass pellets are very ‘fossil-fuel efficient’; i.e. the amount of fossil fuel used to generate the pellets is small compared with the potential bioenergy in the pellets (Figure 9).

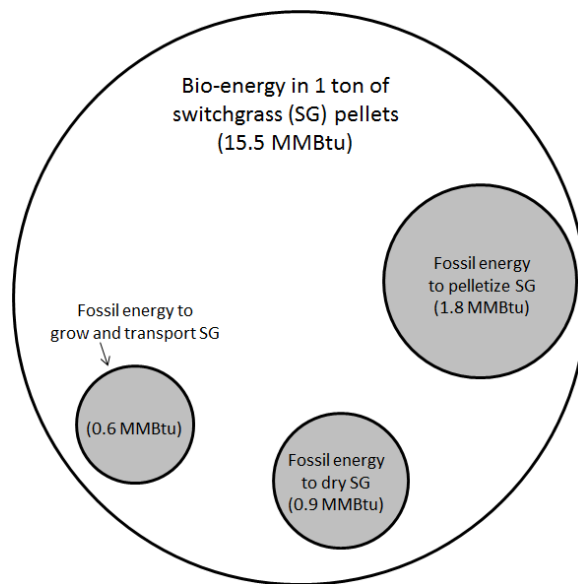


Figure 9 Potential bio-energy and embodied fossil energy in one ton of switchgrass pellets. Bio-energy content value from FPL 2004.

Because of the high net bio-energy content of switchgrass pellets, the use of switchgrass for fuel would offer a significant global warming potential advantage over fossil fuels such as natural gas (Figure 4). This life-cycle assessment scenario suggests a reduction in global warming impact of over 80% for switchgrass pellets versus a natural gas alternative. The Energy Independence and Security Act of 2007 requires a cellulosic biofuel to provide a 60% reduction in greenhouse gas emissions versus fossil fuel alternatives (EPA 2012); however this calculation involves consideration of land-use change impacts that were not considered here.

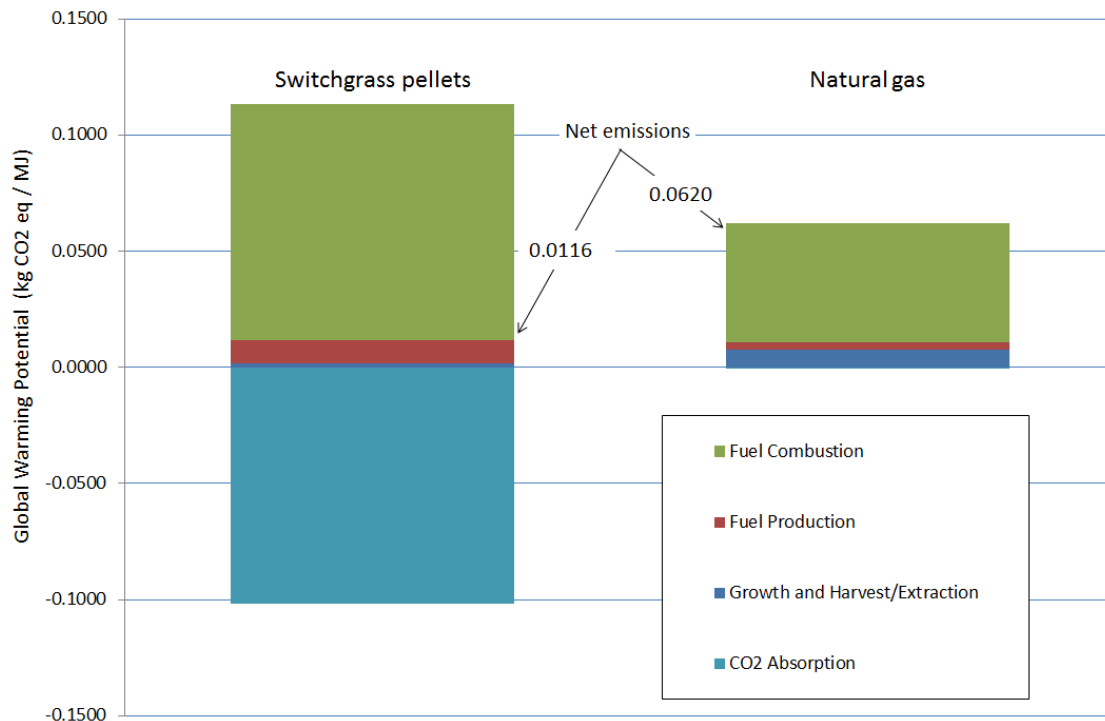


Figure 10 The global warming potential of switchgrass pellets and natural gas, by life stage. Transportation of the fuels to the combustion facility and their relative combustion efficiencies are not considered.

3.8 Summary

This study presents a cradle-to-gate life-cycle inventory for the switchgrass pellets in the Southeast region of the United States. Data from a survey of switchgrass farmers was combined with an estimate for drying energy and inventory data from the pelletization of wood residues. The primary input for the growth and harvesting of switchgrass is nitrogen fertilizer; however, other fuels and chemicals add to the environmental burden of this process. The primary input for manufacturing pellets is electricity and, because electricity is mostly generated from nonrenewable and fossil fuels, this input significantly

impacts the carbon balance of switchgrass pellets. However, the potential bio-energy in the pellets is more than five times the total fossil energy used to create them. Switchgrass pellets, if used as a fuel in place of natural gas, could result in an >80% reduction in global warming potential.

CHAPTER 5 – PROSPECTS FOR INTEGRATING LCA INTO U.S. POLICY DEVELOPMENT AND IMPLEMENTATION

Introduction

Europe and other countries are increasingly using life-cycle information to directly develop governmental policies at national and regional levels. American policy makers have been slower to adopt LCA for a variety of reasons, perhaps the most significant being that American environmental policy has been formulated and optimized largely for single issues rather than through holistic approaches to environmental management (e.g., Clean Air Act and Clean Water Act) (Schenck 2010). There also is a clear difference between Europe and the United States in how and where LCA methodologies are applied. While public adoption of LCA in the U.S. has been focused primarily on energy (fuels), Europe has focused their LCA applications on more non-energy product systems. There are life-cycle applications to product systems in the United States; however, these applications are mostly conducted by private industries evaluating their own products.

Many countries outside the United States use life-cycle assessment for eco-labeling and procurement programs and also employ mechanisms such as eco-taxes, waste reduction targets, and packaging waste reduction programs that take advantage of life-cycle information for waste management policy. For example, in 1992, Europe created a regulated eco-label under Council Regulation (EEC) No. 880/2, which established a voluntary eco-label scheme that was intended to promote products with lower life-cycle environmental impacts and provide consumers with the information.

LCA is rapidly growing in importance in product development, as companies realize the advantages of taking a holistic look at their products' environmental impacts. This increased popularity among industry is illustrated in a GreenBiz 2011 article, "Transparency, Regulations Drive LCA Popularity" (Bardeline 2011). This is important because as the increased relevance on LCA by industry will increase confidence in its use by government.

There are several areas in U.S. policy where LCA could add value. LCA has both advantages and challenges of using LCA in policy, as this Chapter will first explain. This Chapter will then explore how and where LCA can fit in the legislative policy-making process (problem identification, formulation, adoption, implementation, and evaluation). In 1997, MaryAnn Curran, now the director of EPA's Center of LCA Research, reviewed the use of LCA in government policies (Curran 1997). She identified three main areas of U.S. public policy use, or have the potential to use, LCA for decision-making:

- product-oriented policy;
- waste management policy; and
- process-oriented policy

This paper will explore how LCA can be applied in both the legislative and administrative application of these types of policies.

Because the Energy Independence and Security Act (EISA) of 2007 is the only existing federal legislation that requires the use of LCA, it will be used to illustrate the implementation of LCA in both the legislative and administrative

policy processes. Other examples of current laws are given that could integrate LCA through administrative functions including the Toxic Substance Control Act (TSCA), the National Environmental Policy Act (NEPA), and the Clean Air Act (CAA). Finally, because EPA is the primary federal agency that would use LCA as a tool in their administrative policies because LCA measures environmental impacts, their strategic vision of LCA implementation is discussed to inform what barriers and opportunities other agencies may face when using LCA.

Advantages and Challenges of Life-Cycle Assessment

The intent of life-cycle assessment is to provide a holistic summary of impacts to the environment. LCA provides a systematic estimation of the environmental consequences of every stage of a product's manufacture. There are several advantages to integrating LCA in the policy-making process.

LCA can be used for to identify '*process hotspots*': documenting the the component(s) of a process that are most significant in terms of environmental impact. This kind of information can be important for those situations where desired outcomes (e.g. clean air) are pursued by regulating processing components (e.g. emissions controls).

LCA can be used for *product comparisons*, to provide fair, holistic ways of examining more than one product or process option. For example, products such as paper, plastic, and canvas grocery bags can be compared using LCA to determine which has the lesser environmental impact. In fact, LCA was first developed in the United States to evaluate bottling options for the Coca-Cola

Company. Products such as wood can be compared to steel or other composite alternatives. Even recycled products can be compared to their original product's process to show the environmental advantages (or disadvantages) of different recycling techniques.

LCA is an *adaptive* tool that can address a variety of conditions, e.g. geographical differences. For example, an LCA of a product from Kentucky may reveal more life-cycle environmental impacts than the same item produced in Oregon. This is because these two areas have different energy production sources (coal in Kentucky vs. hydroelectric in Oregon) that have different environmental impact levels. LCA can consider these geographical differences and provide more complete and accurate information to policy and decision-makers.

LCA can provide many types of environmental impact information through *standardized impact categories*. Common impact categories that are reported for LCA are: Global Warming Potential, Ozone Depletion, Acidification, Eutrophication, Photochemical Smog, Ecotoxicity, Habitat Loss, Land Use, and Biodiversity. The U.S. EPA has specifically developed methodologies for evaluating these impact categories (among others) in U.S. conditions with the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) (Bare 1992). The development of such a tool tailored for U.S. conditions further formalizing impact assessment methods. This kind of a tool also provides a uniform and transparent basis on which to evaluate alternatives.

Standards and information used for life-cycle science are becoming *easier and more accurate* to perform due to improvements in LCA software and databases. A wide variety of software packages have been developed, including OpenLCA, a free and open-source program (GreenDeltaTC 2010). These programs allow for easy movement of individual unit processes such as transportation methods (e.g., truck, train, barge) or certain unit processes such as regional electricity production to be attached. These tools also allow for sensitivity and uncertainty analyses that can help identify key data and assumptions that influence results. In conjunction with these software advances, public databases are more open and shared across organizations. Commercially available life-cycle databases such as USLCI and Ecoinvent are rapidly growing (Ecoinvent 1998, NREL 2012). The United States Department of Agriculture has even started the development of a new LCA database (LCA Digital Commons) that focuses on making USDA data (field crop production data, irrigation data, farm equipment operation data, and chemical input data) more accessible to the LCA community (USDA 2011). These advances make LCA significantly easier to perform on a wide variety of products and systems.

While LCA offers potential advantages, there are also challenges. There are concerns that life-cycle information is *too adaptive* and can be molded to produce desired results. For example, if two different input datasets exist when performing an LCA on a particular product and one set of input data shows a significantly higher toxicity impact, the lower input dataset could be used to

achieve a desired result. In regards to this kind of application to policy, “political actors tend to use LCAs in a polarizing way. LCAs are easily misused due to their apparent objectivity, and the quantitative and black box nature of their results” (Remke M. Bras-Klapwijk 1998, p. 333).

Familiarity with a *jargon-filled and expert-driven* process such as LCA can present problems when presenting results. LCA results are often confusing those unfamiliar with LCA concepts. For example, results are often presented based on input and output flows of a certain system boundary (defines what processes are included) and follows a functional unit (defines what is being studied). There are also several potentially unfamiliar impact categories (e.g., global warming potential, ecotoxicity) that represent a measurement score from various outputs to nature. Allocation methods that determine how to distribute the environmental impacts further complicate the presentation of the results.

While LCA is becoming easier to implement on products and services, assessments remain *time-intensive and burdensome* when data are not readily available. Life-cycle data collection can be an arduous process, especially for products that have complex manufacturing processes and a large number of inputs and outputs. LCA can also be an expensive task. Most industries hire LCA practitioners who have expertise in data collection and LCA software.

The *lack of accurate inventory data* (e.g. input and output data for processes and systems), however, is perhaps the largest challenge to advancing LCA in public policy. The collection and expansion of life-cycle inventories will

gradually drive down the costs and time requirements. However, as conditions change there are concerns with the need to update inventories based on new conditions. Uncertainty about the data selected also presents concerns. In many cases, life-cycle inventories rely on survey data that are unverified and/or incomplete. Even further, there are always concerns of critical oversights that can be made when collecting data. For example, for a life cycle inventory collecting input data on a co-product, the manufacturer may report electricity consumption based on the their entire manufacturing facility instead of what is needed (electricity consumption for just the co-product process) or vice versa. This kind of oversight can make a huge difference in the impact results.

A number of important *assumptions* drive LCA results and may not be reported with the results, or can bias the result in favor or against a particular outcome. Sometimes input or output data are not available for collection and needs to be estimated or assumed. For example, a product may be transported in a variety of ways between manufacturing stages. It could be assumed the product is transported by truck, but in reality it could be transported by railway. These have very different impacts associated with each. Other assumptions such as data weighting and allocation methods among co-products can influence impact results. For example, if a manufacturing process creates a primary product and another less valuable co-product, a choice in the allocation of environmental burdens can be made. Environmental burdens can be allocated by either mass or by value. Mass allocation assigns the associated environmental

burdens by how much raw material is going to the primary product and co-product. Value-based allocation assigns the associated environmental burdens relative to the value of the end-product. Usually the primary product is economically valued more than the co-product, and therefore is assigned more of the environmental burdens. This kind of information can be omitted from the assessment and can be very important in the interpretation of the results.

Curran (1997) described some barriers to integrating LCA into public policy. Many of these barriers have diminished since 1997; others remain significant in applying LCA to public policy (Table 12).

Table 12 – Barriers to the Application of LCA in Developing Public Policy

Barriers to the Application of LCA in Developing (Public) Policy	Diminished Barrier since 1995
1) The lack of (inter)nationally agreed upon methods for evaluation and weighing the results of LCA's	X
2) Companies' concerns with confidentiality preventing consensus building or reducing the transparency information and hence the credibility of LCA results	
3) Decision makers, general public, the press, etc., want LCA to be presented in a very simplified format from which an obvious "winner" emerges.	X
4) A network is lacking which would make the results of LCA's available to the public and government. Information on LCA, in general, needs to be more accessible.	X
5) Current government policy encourages partial initiatives. Government office can be segmented by media concerns (air, water, solid and hazardous waste) or by topical interests. [for example, EISA's segmentation of life-cycle concerns of air emissions]	
6) Existing regulations in some countries are a major disincentive for the adoption of LCA. Regulation provides penalties instead of incentives.	
7) Layers in state, regional, or local governments make communications very difficult.	
8) The international dimension of material and product systems forms a barrier. The government has taken limited action to support and establish forms of cooperation.	
9) Short deadlines, caused by a lack of planning, set by politicians, do not allow for the time needed to conduct quality assured LCAs.	
10) Government offices have not adopted life-cycle management systems within their operations.	X
11) Governments lack a framework for integrating information with other factors that must be considered in the decision-making process, such as economics and societal needs.	
(Curran 1997; Oesfold Research Foundation 1995)	

Some of the barriers listed in Table 12 have diminished because improvements in LCA practice, government involvement, and increased public interest since 1995. The first barrier identified was the lack of (inter)nationally agreed upon methods for evaluating and weighing LCA results. Global collaborations such as the joint program between the United Nations Environmental Programme and Society of Environmental Toxicology and Chemistry, “The Life-Cycle Initiative” (UNEP/SETAC 2012) and the acceptance of international standards (ISO 14040-4) has strengthened acceptance of uniform LCA methodologies. Nonetheless, concerns with variations in analysis and variable interpretations of results remain as challenges for LCA integration into public policy.

Another barrier that has somewhat diminished over the past decade is the ability to present LCA results in a simplified and more readily-understood manner, allowing easier comparison of alternative products and processes. LCA is a complex assessment method that describes a range of impacts (or impact categories). In this regard, naming clear “winners” can be subjective because it depends on which impact category is selected (e.g., something could have a low global warming potential but a high ecotoxicity impact). However, LCA is increasingly being used to present information in a simple and relatable way. For example, many countries have developed “environmental product declarations” to label the environmental impacts of a product. The intent of these environmental product declaration programs as well as the European eco-label

program is to use life-cycle information to portray impacts of products in a consistent and understandable way (European Commission 2012). At the same time, some view these simplified means of conveying life-cycle information as misleading because there is no way (without making important assumptions) to assign or quantify a singular environmental “score” on a product or system. In addition, these EPD programs are still developing and many policy-makers and scientists are reluctant to accept the information they provide (Salzman 1997; Clift et. al. 2005).

Another barrier that has been diminished in the last 15 years is the lack of a network of LCA information and poor accessibility to LCA information. The rapid advances in LCA software development and database expansions have changed the way LCA information is accessed. Commercially available databases such as the U.S. LCI database and Ecoinvent are quickly expanding (Ecoinvent 1998; NREL 2012). Other public projects such as OpenLCA and LCA Digital Commons are promoting efforts to expand accessible life-cycle inventory data, particularly in the United States (GreenDeltaTC 2010; USDA 2011).

Even with this improvement in access to data, the American Center for Life-Cycle Assessment (ACLCA) acknowledges, “the biggest research challenge for LCA lies in the lack of life-cycle inventory data” (Schenck 2010). Along with the lack of inventory data come data quality concerns. Many LCA database administrators seek data from LCA researchers and have their own data quality standards (mostly aligning with ISO’s data quality standards). As databases are

expanded, however, more concerns with the quality (uncertainty, following standards, assumptions) follow.

The last barrier that has diminished over the past decade has been the lack of LCA's use by government agencies. Specifically in the United States, the EPA is increasingly introducing LCA in their administrative actions, such as the Energy Independence and Security Act of 2007. The Department of Energy has developed a methodology to evaluate fuel systems using LCA (the GREET model). This barrier has not been completely eliminated in the United States; however, it has somewhat transformed from not adopting LCA life-cycle management systems at all to being extremely hesitant (compared to Europe, for example) to adopt life-cycle information for agency policy actions.

Roles for LCA in the Legislative Policy Process

Legislative policy is action that is mandated by law. Legislative policy prescribes what has to be done but not how to do it. Administrative policies are procedures agencies develop to either meet legislative requirements or to meet other goals of the agency. The next section introduces potential roles for LCA in legislative and administrative policy processes.

The legislative policy process comprises five primary stages: problem identification, policy formulation, policy adoption, policy implementation, and policy evaluation. LCA could play a role in the problem identification, policy implementation, and policy evaluation stages.

Problem identification, the issues that require some form of policy intervention are identified. This is often initiated by a public concern that is brought to the attention of policy and/or decision-makers. Given that LCA provides information sometimes otherwise unseen by other assessment tools, it can play a role in identifying public problems. For example, public concerns and debates centered on solid waste issues such as recycling versus energy recovery in the mid 1990s. LCA was proposed as a way to determine the problems (*“hot spots” identification*) within sustainable waste management systems and to guide policy-makers with scientific and technical evidence (McDougall et al. 2001).

During *policy implementation*, government agencies are mandated to implement the policy by establishing procedures, budgeting funds, and educating the public about policy. Most often during the implementation phase, agencies are charged with giving explanations to the public (especially to those affected) on the reason for the policy action. LCA can help in establishing procedures and *educating the public* about the policy decision and how implementation will lead to the desired outcomes.

During the *policy evaluation* phase, LCA can be used as a *comparative tool* to measure this policy effectiveness with comparisons of before and after policy implementation.

The only example of LCA being incorporated in the federal policy process is the Energy Independence and Security Act (EISA) of 2007, which amends the

Clean Air Act to require that some new biofuels undergo life-cycle analysis to meet certain thresholds of greenhouse gas emissions reductions (Hagan 2012). EISA specifies LCA as the methodology determine if a fuel meets the thresholds for emissions reductions goals. The choice of including LCA for the method of calculating greenhouse gas emissions was debated between the U.S. House of Representatives and Senate during the formulation phase. As they were formulating this policy, there were concerns of defining “life-cycle greenhouse gases” and whether to include indirect land use change impacts. Ultimately, the Senate demanded that these conditions be met before they would pass the bill (L. Schmidt, EPA Office of Radiation, personal communications, January 20, 2012). During the policy implementation phase, LCA is being used as a tool to aid in both the evaluation of new advanced biofuels as well as the effectiveness of outcomes from creating the thresholds.

Potential Roles for LCA in Current Federal Policies

Several existing policies could integrate life-cycle concepts within the administrative functions of the policy. For example, the Toxic Substance Control Act (TSCA) does not require LCA to be performed on products or chemicals. Other much larger command-and-control regulations such as the National Environmental Policy Act (NEPA) and Clean Air Act (CAA) have components that could benefit from life-cycle information and reporting. This section will take a look at these legislative acts and explore ways LCA could add value to the achieving policy goals.

Toxic Substance Control Act (TSCA)

Enacted in 1976, TSCA provides EPA with authority to require reporting, record-keeping, and testing of, and to impose restrictions on, chemical substances and/or mixtures (U.S. Congress 1976). In this regulatory framework, chemicals must be inventoried by the EPA before manufacture or import. The EPA establishes this inventory by requiring a pre-manufacture notice (PMN) on all chemicals not on an exemption list. This PMN provides information on health and environmental impacts. The EPA has most recently made this inventory available on the web at www.data.gov. “PMN submissions require all available data on chemical identity, production volume, byproducts, use, environmental release, disposal practices, and human exposure” (EPA 2012). The PMN information requires test data on health and environmental effects of new chemical substances and suggests and encourages the inclusion of information that substantiates claims that the chemical in question helps in pollution prevention and/or has recycling benefits.

Life-cycle analyses could help substantiate claims of new chemicals that would prevent pollution and/or provide recycling benefits. TSCA specifically focuses on single-source exposure types of toxicity or “acute toxicity” (e.g., LD50 or median lethal dose of a toxin required to kill 50% of a tested population). While LCA will not provide this type of information, it would help to evaluate holistic, potentially multi-source toxicity. TRACI, for example, calculates all of the inputs from all stages of production (multi-source) from different times and places. This

kind of perspective can show how some chemicals acute impacts could be relatively small when compared to multisource, holistic impacts (associated with electricity production, for example).

However, it would be impractical for EPA to require the applicant to conduct an LCA on every PMN submitted. The LCA process is becoming faster and more convenient as data quality and software development improves, however, EPA receives roughly 2,500 PMNs every year and TSCA prescribes a strict timeframe (90 days) for the turnaround of admissions. LCA could still be included in the process, however, as a methodological recommendation for submitting data in the PMN process, especially for chemicals that have readily-available data.

National Environmental Policy Act (NEPA)

The National Environmental Policy Act (NEPA) of 1969 requires federal agencies to evaluate environmental impacts prior to taking action. The purpose of NEPA is to promote informed decision-making by federal agencies by making detailed information concerning significant environmental impacts of proposed projects available to agency leaders and to the public. NEPA establishes a process whereby federal agencies conduct an environmental impact assessment (EIA). EIA is a systematic process that examines the environmental consequences of proposed actions with the goal being focused on prevention of environmental harm (Glasson, Therivel et al. 2005).

While the EIA process is widely considered to be a systematic approach to environmental assessment, there are several complications in the application of this systematic approach. Among the largest problems is there is no standardized process for conducting an EIA. The Council of Environmental Quality provides a fairly general template for EIA, but allows considerable flexibility to the agencies. Each agency has different methods to meet the EIA requirement. Using LCA as a tool to determine many of the environmental impacts NEPA seeks to disclose can help achieve the systematic goals of the NEPA process by providing a more uniform way to account for cumulative impacts and allows for comparing the decided upon alternative actions.

Environmental Impact Statements (EIS), as required by NEPA, many times do not address or evaluate cumulative impacts (Schenck 2009). EPA recognized the need to evaluate cumulative impacts in a report in 1999 called "Consideration of Cumulative Impacts In EPA Review of NEPA documents" (EPA 1999). LCA could replace "many of the EIS environmental analyses and would decrease costs, increase the speed and comparability of studies, and address the issue of cumulative effects" (Schenck 2009 p.3). NEPA reviews can be required for many similar projects such as the development of new power plants, for example. Each project requires a new NEPA process, but much of the analysis is repeated to account for specific geographic and other conditions. In this regard, much of the information LCA can provide can be replicated using new the new project-specific conditions. This could increase the speed and

decrease costs for analysis. LCA is a tool that becomes easier to perform the more it is used because as inventories are collected and consequently databases are expanded, LCA allows for different unit processes to be treated separately or rearranged as desired. For example, a life-cycle inventory on transporting coal from a coal facility to a power plant can be attached to other inventories that use the same transportation method—this unit process doesn't necessarily have to be collected again.

Some concerns do arise with the possibility of integrating life-cycle analyses into NEPA requirements. Eccleston (1999), a NEPA and environmental consultant for over thirty years, discusses some of these concerns and identifies some factors that would be useful in determining if an LCA should be integrated with NEPA procedures. These factors are: *significant impacts, reasonably foreseeable impacts, ripe for decision, and NEPA's intent—environmental planning and decision-making, unresolved conflicts, and a clear basis for choice among options*. These factors are explained below.

NEPA procedures lay out three primary categories of review: categorical exclusion (predetermined categories of actions that have been found to have no significant individual or cumulative impact), environmental assessments (review for actions that cannot be categorically excluded and/or it is uncertain that the action would have significant impacts), and environmental impact statements (for actions that could significantly affect the environment and should be evaluated in a complex analysis that presents alternatives development). Eccleston proposes

that LCA is only feasible to be integrated with NEPA requirements inside the scope of a project that causes *significant impacts* and requires a full environmental impact statement. In other words, the scope of categorical exclusions and environmental assessments are usually shorter evaluations and generally should not require an LCA because categorical exclusions have already been found to have no significant environmental impact.

The next factor useful in determining if an LCA should be integrated with NEPA procedures are *reasonably foreseeable impacts*. “Environmental impacts need only be evaluated to the extent they are deemed reasonably foreseeable. The requirement to investigate impacts does not extend to impacts deemed remote or speculative” (Eccleston 1999, p.45). This is most likely because LCA is a data-intensive process and not a tool intended to solely estimate impacts but quantify them based on observable data. This observation illustrates an important conflict with LCA in that environmental impacts can be remote in time and space, especially when factors such as indirect land-use change are being considered.

According to Eccleston, LCA integration with NEPA should also be considered when the environmental impact statement is *ripe for decision*. This is to say that LCA should only be applied to a proposal that has matured to a stage where enough information exists to support an LCA analysis. This suggests that environmental impact statements, at maturity, hold enough detailed analysis to allow an LCA to be applied and can significantly strengthen the proposal. At this

point, LCA could help distinguish environmental impacts between alternatives development, or supplement existing analyses to strengthen alternatives development. For example, if one alternative action to the proposed plan would significantly reduce the associated life-cycle greenhouse gas emissions, LCA would be a useful tool to document this.

LCA is a tool that has historically been used to evaluate *unresolved conflicts* in the use of environmental resources (e.g., energy-use in recycling, energy balances in biofuels). “An LCA therefore might be justified if it would help settle or clarify unresolved conflicts in the commitment of environmental resources” (Eccleston 1999, p.45). For example, a proposed plan of building a new coal-fire energy plant could be weighed against an alternative of building a nuclear power facility using life-cycle environmental impact analysis. Some of the unresolved conflicts between the two comparisons could be distinguished from the impact results of an LCA. LCA is a tool that could potentially look beyond just the construction impacts of these facilities, but also the cumulative effects of the facility’s use.

Finally, much of the NEPA process is focused on developing alternatives that might have a lesser impact to the environment. LCA could help to identify *a clear basis for choice* among options. One of the main intents of NEPA is to provide alternatives to choose from. Once the alternatives have been identified, LCA could be used to compare impacts and thus help to identify the best choice among several alternatives (e.g., coal power plant vs. nuclear power plant).

Clean Air Act (CAA)

Enacted in 1970, the CAA is a federal law that regulates air emissions from stationary and mobile sources. EPA is authorized under this law to establish National Ambient Air Quality Standards (NAAQS) to regulate emissions of six “criteria” air pollutants. The current Act established a permit system to address acid rain, ozone depletion, and toxic air pollution. The Energy Independence and Security Act (EISA) of 2007 amended the CAA to require newly introduced biofuels undergo life-cycle analysis to meet certain thresholds set by the EPA. However, the EPA is currently developing methods to regulate GHG emissions under the CAA because of a decision from *Massachusetts v. EPA*, where the United States Supreme Court held that greenhouse gases (GHGs) fits the definition of an air pollutant (2007)⁷ “As greenhouse gases become subject to regulation under the Clean Air Act, taking lifecycle emissions into account could help encourage innovation in reducing emissions associated with electricity generation” (Hagan 2011). Currently, the CAA ignores most life-cycle emission considerations.

In the mid 1990s when life-cycle information was gaining popularity and standards were being developed, the EPA’s Office of Pollution Prevention and Toxics initiated a test case “to investigate the possibility of using a life-cycle approach in developing a MACT (maximum achievable control [emissions] technology) standard under the CAA” (Curran 1997, p.42). In this particular test

⁷ 549 U.S. 497, 534 (2007); see 42 U.S.C. §7545 (c)(1) (2006)

case, the selected MACT examined alternative solvents used in degreasing operations. The test was abandoned because of time constraints and methodological issues (LCA methodologies and standards were just beginning to be refined and accepted at this time) but the idea that LCA has a role in of developing MACT standards, however, was a good one. The maximum achievable control technology, using conventional evaluation procedures, may not be the best holistic solution. For example, emissions control systems that depend on electrical energy (e.g., electrostatic precipitators) reduce emissions at the stack but may result in increases of air pollution where the electricity is generated.

Administrative Policy for LCA at EPA

There are many opportunities within state and federal agencies for integrating LCA information in administrative policy to meet a variety of different goals (e.g., environmental sustainability, transparency, evaluating requirements). Perhaps most opportunities exist within the EPA. EPA has been a driving role in the LCA methodology and standards development, including the development of the TRACI impact assessment model. It is most likely that future advances in LCA will continue to be driven by EPA as it has the most to gain (or lose) from using LCA. If EPA adopts LCA at the federal level, this may influence the use of LCA by state environmental protection agencies as well, because many of the policies that state environmental protection agencies develop are guided, or may be required, by policies first set at EPA.

Because of the importance of EPA's involvement in the development of LCA as a policy tool in the United States, it is helpful to examine not only the history of LCA in EPA policy but also its plans for LCA in the future. EPA has developed a framework of plans for the advancement of LCA in the future that go beyond just using it as a tool. This is perhaps in response to the nature of LCA and some of the challenges previously discussed in this Chapter. This section discusses the internal framework of strategies the EPA has developed for their own administrative policy to advance LCA within the agency.

In 2010, EPA commissioned the National Research Council (NRC) to conduct a study on how to best make sustainability operational inside of the agency. The report identified various tools and approaches to sustainability that were currently used, as well as tools that needed to be adopted. One of the primary conclusions from the report was that LCA is a key tool the agency could use to assess and manage sustainability (National Research Council 2011). Along with other tools, such as risk assessment, environmental justice tools, sustainability impact assessment, LCA was identified as a means to better manage and assess sustainability efforts within the agency. "Such tools can provide a uniform and transparent basis on which to evaluate alternatives" (National Research Council 2011).

In response to this NRC report, MaryAnn Curran (the director of the Life-cycle Assessment Research Center at EPA) and her colleagues identified four ways LCA could be advanced within the agency:

- Using LCA to inform policy-making more broadly,
- LCA education & outreach,
- improving the quality and accessibility of LCA data and tools,
- and international engagement in LCA.

Using LCA to inform policy-making more broadly within EPA

While EPA is using LCA as a tool to implement EISA requirements on newly advanced biofuels, EPA also recognizes LCA can be applied more broadly in other areas. Four areas were identified where EPA could use LCA to better inform both decision making within the agency: *sustainable products, sustainable materials management (SMM), chemical safety for sustainability, and energy systems research* (M. Curran, personal communication, Jan 9, 2012). In regards to the first two areas of sustainable products and sustainable materials management, a separate inter-agency workgroup issued recommendations in a 2009 EPA publication, “Sustainable Materials Management: The Road Ahead” (EPA 2009). The primary recommendation in this report is that the EPA should expand the focus of existing environmental programs to encompass life-cycle materials management more holistically.

Another initiative identified by Curran to help inform decision-makers describes the development of a research program on chemical safety for sustainability. “The purpose of this research program in EPA’s Office of Research and Development is to help move towards sustainable use of chemicals” (M. Curran, personal communication, pers. comm. Jan 9, 2012). More opportunities

are identified for state waste and chemical programs to use life-cycle information for decision-making.

Finally, the last initiative for introducing more life-cycle scopes is for “Energy Systems Research”. The Office of Research and Development is in the process of designing a new program for Air Climate and Energy (ACE) to address increasingly complex environmental issues. To achieve this goal, more integrated, “transdisciplinary” approaches would be needed. To this extent, this initiative plans for ACE to incorporate life-cycle impacts in their development of methods, models and data for energy systems to assess impacts of air pollution and climate change, among others. U.S. Department of Energy’s Argonne National Laboratory has already developed a LCA model to examine the life-cycle energy and environmental impacts of vehicle technologies and transportation fuels (the GREET model).

Education and Outreach

Education and outreach is also a top priority for incorporating LCA into EPA’s sustainability activities. Three specific areas to be addressed are internal education and outreach, external education and outreach, and web presence (M. Curran, personal communication, Jan 9, 2012). Concerning *internal* education & outreach, the Office of Research Development at EPA already offers classes on lifecycle assessment within the agency. These internal educational opportunities are meant to enable EPA staff to provide guidance on interpretation and information uses for decision-making. EPA recognizes that there are

opportunities for LCA at EPA that can only be made use of if staff knows that the tool exists and how it works. Given the size and breadth of work at EPA, internal education and outreach is important to LCA's inclusion as a tool inside of a broad range of administrative policy. Internal education and outreach is also important given the characteristics of LCA concepts. To those unfamiliar, LCA jargon can sometimes cloud the presentation of the results. Familiarizing EPA staff, even at an elementary level, is important for encouraging LCA's advancement internally.

External education & outreach is also very important for advancing life-cycle concepts within the Agency. EPA is in a good position to disseminate guidance on which LCA tools are best applied in which circumstances as well as describe best practices in life-cycle practices. The information EPA currently provides on life-cycle thinking is highly referenced and sought. Online materials and illustrative examples of LCA success stories are being integrated into the existing LCA website (<http://www.epa.gov/nrmrl/std/lca/lca.html>) to accommodate the increasing popularity of, and curiosity about, life-cycle thinking. According to Curran, this website is regularly among the top five visited websites in EPA's National Risk Management Research Laboratory (NRMRL) family of web addresses.. This inclusion of external outreach to EPA's strategy to advance LCA illustrates the recognition that LCA is an ever-expanding methodology and instigating dialogue has the potential to spur these new ideas as well as promote LCA's use. The American Center for Life-Cycle Assessment (ACLCA) has recently made education and outreach for LCA in America a top priority. Working

with the ACLCA, EPA wants to collaborate in education opportunities for internships, externships, and web forums to promote dialogue in the LCA community.

Improving the quality and accessibility of LCA data and tools

LCA is very data-driven. In order for LCA to advance and successfully be used, EPA thinks it is essential to continue to improve the quality and especially the accessibility of LCA data and tools. “Increasing the quality and availability of data and tools for inventory and impact analysis has the potential to catalyze significant increases in use of LCA both inside and outside of EPA” (M. Curran, personal communication, pers. comm. Jan 9, 2012). Two important initiatives are being pursued at EPA to increase quality and availability of LCA data, by improving inventory databases and models and by improving impact data and models. One project for improving life-cycle inventory databases is the consideration of the creation of an LCA Digital Commons in collaboration with the President’s Office of Science and Technology. This venture would make federally held LCA data readily available for use in LCA. EPA thinks the completion of such a project would be a very significant step in the right direction in providing accessibility to LCA data for both public and private sectors.

As the administrator of the only US-specific impact assessment method, the Tool for the Reduction and Assessment of Chemical and other environmental impacts (TRACI), EPA has a responsibility for the improvement of impact data and modeling, essential for the improvement of the quality of LCA (especially in

the United States). Areas such as land use and water assessment methods have been identified as priorities for improvement inside this tool (Curran 2012). EPA wants to work with U.S. universities as well as skilled professionals in broad areas within the Agency would help improving these impact areas as well as advocate for life-cycle concepts among research institutions. Concerning impact assessment improvement, merging data from other risk assessment programs could prove useful in impact models such as TRACI. For example, toxicology data acquired by the EPA already for emerging products such as nanomaterials can be used in these impact models.

International Engagement

Much of the world is moving forward with life-cycle concepts, goals, and use in government policy at a much faster pace than in the United States. EPA feels that collaborations with organizations such as UNEP/SETAC's Life-cycle Initiative as well as The European Commission Joint Research Center are important to ensuring the usefulness of LCA methods and expansion of global databases. These collaborations can provide a global platform for encouraging life-cycle practices in the United States and the rest of the world. There is much EPA can learn from these collaborations such as success (and failure) stories from LCA integration into government policy elsewhere in the world. While these recommendations for advancing LCA are tailored specifically for EPA, many of these same concepts can be applied to other federal agencies as well as state environmental protection agencies. EPA's interest and investment into life-cycle

science including these plans for advancing LCA within the agency is illustrative of the complexities associated with implementing it as a tool, especially to guide policy-makers. For the same reasons, EPA's experience and this vision for LCA inside of legislative and their own administrative policies are influential to other agencies and shows the prospects for it to be included in either type of policy.

Conclusion

Life-cycle approaches are increasingly being used to inform decision and policy-makers. While this is especially true in Europe, the United States is slowly integrating LCA policies in legislative actions and within agency administrative procedures. A number of concerns and challenges remain that hinder the advance and further development of life-cycle concepts such as data development and the reliance on assumptions. LCA is a unique tool because of its complex nature (e.g., data-intensive, information variety, adaptability). These complex analyses can provide very valuable information for a variety of stakeholders; at the same time, however, LCA presents potential problems with data quality, manipulation, oversight, assumptions, and estimations.

EISA requires that some new biofuels undergo life-cycle analysis to meet certain thresholds of greenhouse gas emissions reductions. How LCA was included in the policy process of EISA is a good illustration of how it can be integrated into other future legislative policy. Not without challenges, LCA has a potential role in the policy process by: identifying public problems, guiding baseline policy requirements based on scientific and technical evidence and,

evaluating policy effectiveness using comparisons. There are also apparent benefits for the potential addition of LCA in existing policies such as TSCA, NEPA, and CAA.

A separate, but critically important facet of government policy is administrative policies of state and federal agencies. The U.S. Environmental Protection Agency has taken a primary role in adopting, and promoting, the use of LCA in federal policy. The history of EPA's involvement as well as their vision for LCA as a tool for their own administrative policy is an important indicator of the future direction of life-cycle thinking to be used inside of both legislative and administrative policies. EPA's approach to the future advancement is also important because it is likely to influence the adoption of LCA in other state and federal agencies. EPA recognizes that in order for LCA to successfully become a usable tool within their own agency, more should be done than implementation of that tool. Promoting a broader use of LCA to inform policy-makers is key to its inclusion in both types of policy. Education and outreach, internally and externally must accompany the use of the tool. Finally, given that LCA is heavily reliant on data, the continuation of quality data expansion and accessibility to that data is critical for LCA's advancement.

Policy-makers and federal agencies use a variety of informational tools to guide their decisions. Outside of policy, LCA is being used as an informational tool to assess a broad range of products. The inclusion of LCA in both legislative and administrative policy seems to be slowly increasing in the United States, in

most part due to efforts happening at EPA. As EPA seems to recognize, LCA is a tool that will need more than just implementation inside of policy, but also promotion, education, data expansion/accessibility, and time.

CHAPTER 6 - SUMMARY AND CONCLUSIONS

Life-cycle concepts are increasingly being used to develop holistic information for industries and decision-makers in the United States. Countries outside the United States, particularly in Europe, have begun to use life-cycle information as the basis for policy and decision-making in government. While the United States have been relatively hesitant to use life-cycle assessment as the basis for policy design, government agencies are starting to use life-cycle information more and more. Examining the history of life-cycle assessment in America allows for policy implications and opportunities to be identified.

Chapter 2 examines the history of life-cycle assessment in America and identified some challenges that were presented through time. Public policy is largely driven by public interest. Through this historical examination, it was easy to see how public interest drove (and stagnated) the advancement of life-cycle concepts. For example, public interest in waste streams and landfilling issues coupled with interests in energy-efficiency drove LCA in the early 1970s. However, as environmental issues were seemingly being addressed by other legislative actions such as the Clean Water Act and Clean Air Act, interest in life-cycle assessment waned until the 1990's when a surge in interest in several areas (recycling, landfilling, GHG emissions, eco-toxicity) reinvigorated life-cycle thinking in the United States. History also shows the primary challenges and concerns with life-cycle concepts centered on standardization, data availability, and methodological development. A culmination of the successes and failures of life-cycle applications throughout, especially in public policy, can guide the future

advancement of life-cycle assessment in the United States. This chapter provides the history of LCA in America that has not been organized anywhere else in the literature.

Chapter 3 develops a life-cycle inventory for wood fuel pellets in the Southeastern United States and illustrates the types of information available from life-cycle assessment. By surveying wood pellet manufacturers in the Southeastern region of the United States, input and output data associated with the manufacturing process was collected. This study collected data on a gate-to-gate system, from the raw materials collection (wood waste) to bagged pellets. Through this inventory collection, some impact assessment is presented. For example, the global warming potential (carbon dioxide equivalency) is affected the most by the burdens of the raw material (wood waste) production. The embodied bio-energy in one ton of pellets is identified and compared to another competitive fuel, natural gas. Through this analysis, it is easy to illustrate the environmental benefits of using wood pellets for heat fuel rather than electricity or natural gas for example. This is especially true if the environmental burdens are allocated economically as opposed to being allocated by mass. This is because more of the environmental burdens are assigned to the primary product—hardwood flooring which is significantly more valuable than pellets (the bi-product). Either allocation method, however, illustrates that wood fuel pellets are not completely “carbon-neutral” because it takes energy to manufacture the pellets.

Similar to the previous chapter, Chapter 4 develops a cradle-to-gate life-cycle inventory of switchgrass fuel pellets. By surveying switchgrass farmers, input and output data was collected for the growth and harvest of switchgrass. This growth and harvest data replaced the wood fuel raw material and developed a new system process for switchgrass pellets. Just like the previous chapter, some impact assessment is discussed and compared to natural gas as a fuel. For example, the electricity used to pelletize the product makes up for most of the global warming potential (CO₂-eq). The embodied energy in one ton of switchgrass pellets is significantly more efficient than the same energy found in natural gas for example.

Finally, Chapter 5 explores some of the opportunities for the integration of LCA in American public policy both at the federal and state levels. Several areas of policy were identified and discussed for opportunities of LCA integration: Toxic Substance Control Act (TSCA), Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), Clean Air Act (CAA), National Environmental Policy Act (NEPA). The opportunities for LCA in these particular areas of policy range from alternatives development to the improvement best available technologies for emissions. A framework for LCA's integration into policy is presented showing opportunities for LCA in the policy formulation cycle. Also, this chapter discusses a framework of LCA advancement opportunities at the Environmental Protection Agency. This framework builds upon an inter-agency strategy on advancing and promoting LCA within the agency.

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APPENDIX

Acronyms

ACLCA	American Center for Life-cycle Assessment
CAA	Clean Air Act
CWA	Clean Water Act
DOE	Department of Energy
DTSC	California Department of Toxic Substances Control
EAB	Exposure Assessment Branch
EE-IO	Environmentally-Extended Input-Output
EERE	Office of Energy Efficiency and Renewable Energy
EIA	Environmental Impact Assessment
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency
EPP	Environmentally Preferable Purchasing
ETP	Ecological Toxicity Potential
FAL	Franklin Associated, Limited
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GHG	Greenhouse Gas
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
HTP	Human Toxicity Potential
ISO	International Organization for Standardization
LCA	Life-Cycle Assessment
LCI	Life-Cycle Inventory
LCIA	Life-cycle Impact Assessment
LCM	Life-cycle Management
LEED	Leadership in Energy and Environmental Design
LoREX	Low Release and Exposure
LVE	Low Volume Exemptions
MCAT	Maximum Achievable Control Technology
MR	Materials and Resources
MRI	Midwest Research Institute
NEPA	National Environmental Protection Act
NGO	Non-Governmental Organization
NREL	National Renewable Energy Laboratory
NRS	National Research Council
PMN	Pre-Manufacture Notice
REACH	Registration, Evaluation, and Authorisation of Chemicals
REPA	Resource and Environmental Profile Analysis
RFS	Renewable Fuel Standard
SETAC	Society of Environmental Toxicology and Chemistry
TDOT	Tennessee Department of Transportation

TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
TSCA	Toxic Substance Control Act
UNEP	United Nations Environment Programme
USGBC	United States Green Building Council
WEEE	Waste Electrical and Electronic Equipment

VITA

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