Major Systems Feasibility Studies for the McCall Idaho Field Campus

A Thesis

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By

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AUTHORIZATION TO SUBMIT THESIS

This thesis of Crystal A. Van Horn, submitted for the degree of Master of Science with a major in Architecture and titled "Major Systems Feasibility Studies for the McCall Idaho Field Campus" has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

This thesis, named "Major Systems Feasibility Studies for the McCall Idaho Field Campus," explores the feasibility and carbon savings of the major system elements to be incorporated into the proposed Carbon Neutral Environmental Learning Center at the McCall Idaho Field Campus. Considering that buildings contribute a major portion of greenhouse gases, advances in green technology in building design and construction indicate that it is possible to reduce CO_2 emissions in building construction and operation. This thesis explores the various ways the major system components can help the field campus reduce or eliminate CO_2 emissions through advances in green technology, materials, and design.

This thesis is a feasibility study which will examine the carbon offset through using a biomass fueled power generation facility as compared to drawing power from grid-provided electricity and natural gas. This study will also look at three different building materials; straw bale, rammed earth, and cordwood in order to deduce carbon costs of building with these construction materials as well as the pros and cons of building with these materials in McCall Idaho. The carbon offsets from utilizing recycled and salvaged materials is also discussed.

Upon conducting the feasibility analysis, it was shown that there are carbon savings and tradeoffs which prove that the major systems incorporated in the proposed Carbon Neutral Environmental Learning Center at the McCall Idaho Field Campus, can reduce CO_2 emissions through advances in green technology, materials, and design. This thesis serves as a research contribution to the development of the Carbon Neutral Environmental Learning Center. It is a living document and is intended to be used as a reference for the McCall Idaho Field Campus and any other facility wishing to attain carbon neutrality and sustainable design.

ACKNOWLEDGEMENTS

I would like to acknowledge Greg Ohanian, my physics professor at Fresno City College, who never gave up on me. I would like to acknowledge Paul Wack of California Polytechnic State University San Luis Obispo, who gave me my love for both city planning and for sustainable development. I would also like to acknowledge Bruce Haglund and Steve Hollenhorst of the University of Idaho, who gave me a shot at a spectacular project, for being my mentors and guides, and for believing in me when I tried to attempt the near impossible.

I would like to dedicate this thesis to my mother Pam, my brother Alex, the rest of my family and friends, and to Dolores Deteresi and Michael Harman for supporting me and cheering me on. Thank you for all your love and support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

Introduction

This thesis is to serve as a research contribution to the development of the proposed Carbon Neutral Environmental Learning Center at the McCall Idaho Field Campus. It is a living document and is intended to be used as a reference for the McCall Idaho Field Campus and any other facility wishing to attain carbon neutrality and sustainable design. This thesis will specifically analyze three different building methods; straw bale, rammed earth, and cordwood in order to deduce the carbon costs of building with these construction materials. It will look at the pros and cons of building with these materials in McCall Idaho, and this thesis will also look at the potential supply sources for these three building materials. The carbon offsets from utilizing recycled and salvaged materials is also discussed. The other major focus of this thesis is the study of biomass as a main source of power generation. It will look at whether biomass is a feasible approach to power generation for this facility, what the carbon tradeoffs of using biomass power generation are as opposed to using electricity provided from propane and from the city electricity grid that the field campus currently uses, the source of the biomass, and how much biomass will be needed to supply all of the campus energy.

Project Vision Statement:

It is the vision of the University of Idaho, in conjunction with the McCall Field Campus, to bring forth the realization of a Carbon Neutral Environmental Learning Center. It is the hope that this carbon-neutral facility will create awareness for humanity's ever growing need to strive for sustainable development. We envision a sustainable society whereby a well informed citizenry makes decisions based on their willingness and ability to investigate effectively, think critically, and work collaboratively while seeking solutions to complex societal an environmental issues.

Our past has been grand, and our future vision is bold. We see potential for the University to make significant contributions in education well into the future. As a land grant university, we are engaged with Idaho's people in the process of community development, including both human development and economic development. Through interdisciplinary collaboration, it is our goal to expand the capacity and delivery of the University of Idaho's land-grant mission of education, research and outreach, through a state-of-the-art field campus facility by creating a Carbon Neutral Environmental Learning Center at the University of Idaho McCall Field Campus.

The overall project goal is to create a year-round Environmental Learning Center in which all buildings will be constructed with sustainable materials and technology that will surround both adults and children with lessons for environmentally responsible living. The process for creating the buildings will serve as a learning tool for the students who will be involved in designing and building the structures each summer. The Environmental Learning Center will also serve as a research platform for the faculty who will be involved with directing design and construction, employing innovative techniques, materials, and systems. Experts in alternative and carbon neutral technologies may be brought in to help guide the process. Although the workshops will be directed toward university students in Architecture, Landscape Architecture, Forest Products, Interior Design, Bio-Regional Planning, and Conservation Social Sciences, they may also include students in other disciplines, pre-college students, and built environment professionals. The performance of the resulting buildings will be monitored in terms of energy used and produced; water used, saved, collected, and recycled. The performance and efficiency of the Environmental Learning Center will be displayed in real time in the physical buildings and on the web site.

The Carbon Neutral Environmental Learning Center looks to capitalize on the recent advances in green technology in order to pioneer a built environment that seamlessly weaves together green concepts in energy efficiency, building and finish materials, space planning and use, water treatment, and site construction with an emphasis on using the built environment as a model and teaching tool for applied sustainability.

Graduate and undergraduate students specializing in Architecture, Landscape Architecture, Forest Products, Interior Design, Bioregional Planning, and Conservation Social Sciences will work in an interdisciplinary team to plan, design, and build a "carbon neutral" Environmental Learning Center at the McCall Field Campus. It will be imperative to partner with industry professionals and renowned experts to help synthesize and implement a facilities plan for this Environmental Learning Center.

This project will use the built environment as a model and teaching tool for applied sustainability. Considering that buildings contribute to a major portion of greenhouse gases, advances in green technology indicate that it is possible to reduce CO_2 emissions. This project's primary goal is to design a "carbon neutral" Environmental Learning Center. This project is directly related to sustainability and will have a positive impact on the people, prosperity and the wellbeing of the planet as a whole.

Project Involvement:

Due to the complex nature of this project, the design process first began as an interdisciplinary design studio during the Fall semester of the 2006-2007 school year. This studio combined fifth-year architecture graduate students with fourth-year students from landscape architecture, and interior design. The project's initial participants included 36 students, 6 faculty, 5 community stakeholders and 3 industry partners. Represented were the academic disciples of architecture, landscape architecture, interior design, bioregional planning, and conservation social sciences. The community stakeholders initially involved were the McCall Outdoor Science School, Palouse-Clearwater Environmental Institute, McCall High School, City of McCall, and Idaho Department of Parks and Recreation, and the industry professionals who were involved in the project were Epikos Architecture and Land Planning, Sesech Engineering, and Southface Sustainable Construction. At the beginning of the Fall 2007 semester, an EPA P3 Phase I Grant was sought and received in order to help start the process of seeing this project into actuality.

My initial role in this project as a member of the EPA P3 Grant team, began in the Fall 2007 semester. I worked as a graduate research assistant mobilizing diverse resources to meet the project goals and in re-establishing a realistic timeline. My job was to bring together the project participants who were Bruce Haglund, Steve Hollenhorst, Steve Drown, Rula Awwad-Rafferty, Frank Jacobus, Hanna Persson, Jacob Dolence, Jen Kullgren, Lauriel Schuman, Lynne Westerfield, and Gary Thompson. After arranging meetings with the project participants, I was tasked with bringing together a working master site plan that the whole team could agree on, which was accomplished through two design charettes involving all the participants and subsequent revisions of the master plan. In April 2008, Bruce Haglund, Hanna Persson, Jacob Dolence, Jen Kullgren, Lauriel Schuman, Lynne Westerfield, and myself, participated in the in Washington D.C. at the EPA P3 Expo where we presented the project to the upper-level managers of the U.S. Army Corps of Engineers and Department of Amy as well as the EPA P3 award jurors. We came home from the expo with three awards for the project. We received the P3 Honorable Mention, the Green Building Initiative(TM) award, and the YCCOST award presented by the American Institute of Chemical Engineers for the proposal "Architecture as Pedagogy: Interdisciplinary Design and Creation of a Carbon Neutral Idaho Environmental

Learning Center at the University of Idaho McCall Field Campus." In May 2008, Steve Drown, Rula Awwad-Rafferty, Frank Jacobus, and I participated in the Idaho Green Expo in Boise Idaho. Frank Jacobus spoke in a seminar regarding the project, its sustainability aspects, and what benefits the project poses for the state of Idaho.

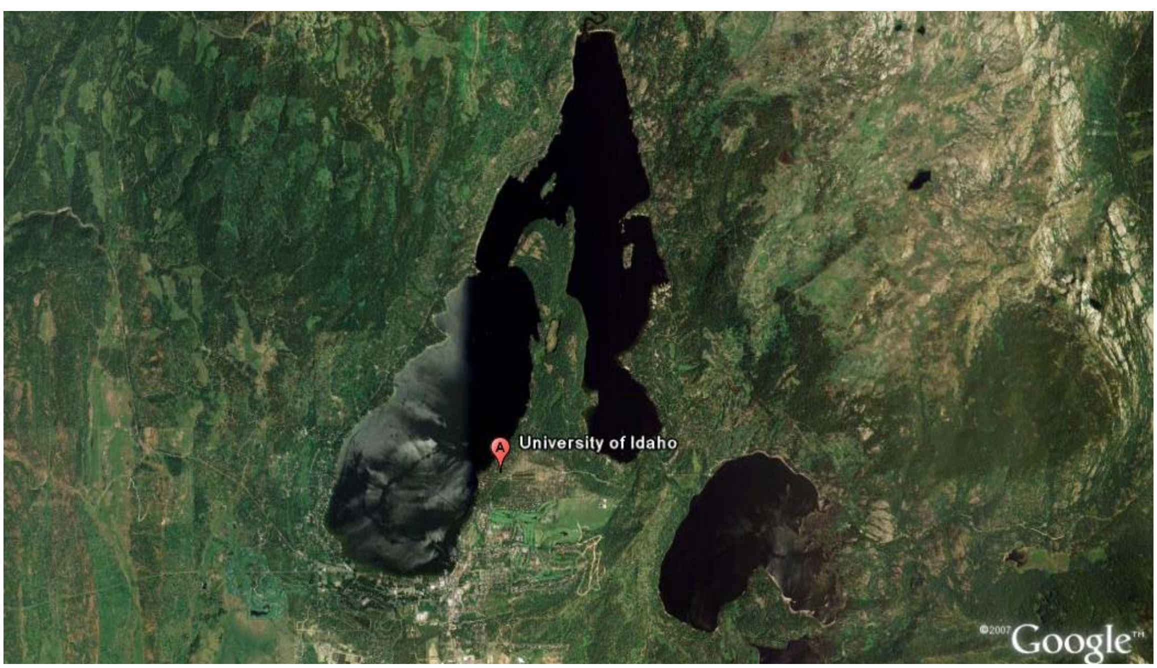
In the 2008-2009 school year, Frank Jacobus began conducting the first building phase of the project, and he is currently leading a group of fourth-year architecture students in a design-build studio. The goal of the studio during the Fall and Spring semesters, is to design one of the guest housing unists, capable of accommodating thirty overnight guests. In Summer 2009, the building is to be constructed on the McCall Field Campus site by the students who had participated in the 2008-2009 design-build studio. Two bunkhouses currently on the campus will be torn down to make room and the resulting material will be reused later for future graduate student and staff housing.

Due to my involvement with the project, I wanted to delve into the feasibility of the campus' major system components, such as construction and power generation, for a "Carbon Neutral Environmental Learning Center." I wondered, what exactly does it mean to be carbon neutral? What are the different ways in which a facility can be carbon neutral or simply save carbon in general? I wanted to explore the tradeoffs of utilizing a biomass energy generation facility, and the amount of carbon this form of energy generation could save. I also felt it prudent to explore several different sustainable construction methods such as cordwood, straw bale, and rammed earth. I was curious as to how much carbon could be saved in the initial construction and over the lifetime of a structure constructed with each of these three methods. It is these major topics which this thesis explores. It is my hope that the information presented in this thesis could be used to aid the on-going design/build project and help others wishing to pioneer built environment projects focused on carbon savings and/or carbon neutrality.

Chapter 1: Project Location and Basic Information

McCall Outdoor Science School (MOSS)

The McCall Outdoor Science School (MOSS), also known as the McCall Field Campus, is an 11-acre site owned by the State of Idaho and leased by the University of Idaho's College of Natural Resources. It is a residential education and conference facility located on Payette Lake within the 200-acre Ponderosa State Park, in McCall, Idaho (University of Idaho, 2007). McCall is located within Valley County which lies within the central portion of the Rocky Mountain Landform Province. The major material found in this area is granite from the Idaho batholiths (McCall Area Chamber of Commerce, 2008). The MOSS is an ideal location for groups to host conferences, meetings, courses and community events. The MOSS provides a relaxed, natural setting with well-equipped facilities, professional hospitality, and an excellent food service. It is also a great place for groups to gather and learn (University of Idaho, 2007).



1.1 A topographic photograph of Payette Lake and the location (marked with a red balloon labeled A) of the University of Idaho owned McCall Field Campus. Image provided from (Google Earth, 2008).

The mission of the McCall Field Campus is to "Enhance the University of Idaho's land-grant mission of education, research, and outreach. The McCall Field Campus serves as a residential learning center that promotes nonpartisan inquiry and understanding of the natural resource and environmental issues and challenges facing Idaho and the American West. The Field Campus and its partners foster scientific literacy, enlightened leadership and open minded dialogue through seminars, policy programs, conferences, leadership development initiatives, graduate and professional education programs, and youth science education programs" (University of Idaho, 2007).

1.2 A student visiting MOSS on the edge of Payette Lake (MOSSIdaho.org, 2008).

1.3 A photo of the view from the dock (MOSSIdaho.org, 2008).

1.4 Students work with other students and field instructors in a teambuilding challenge (MOSSIdaho.org, 2008).

1.5 A photo of students conducting water quality testing on Payette Lake (MOSSIdaho.org, 2008).

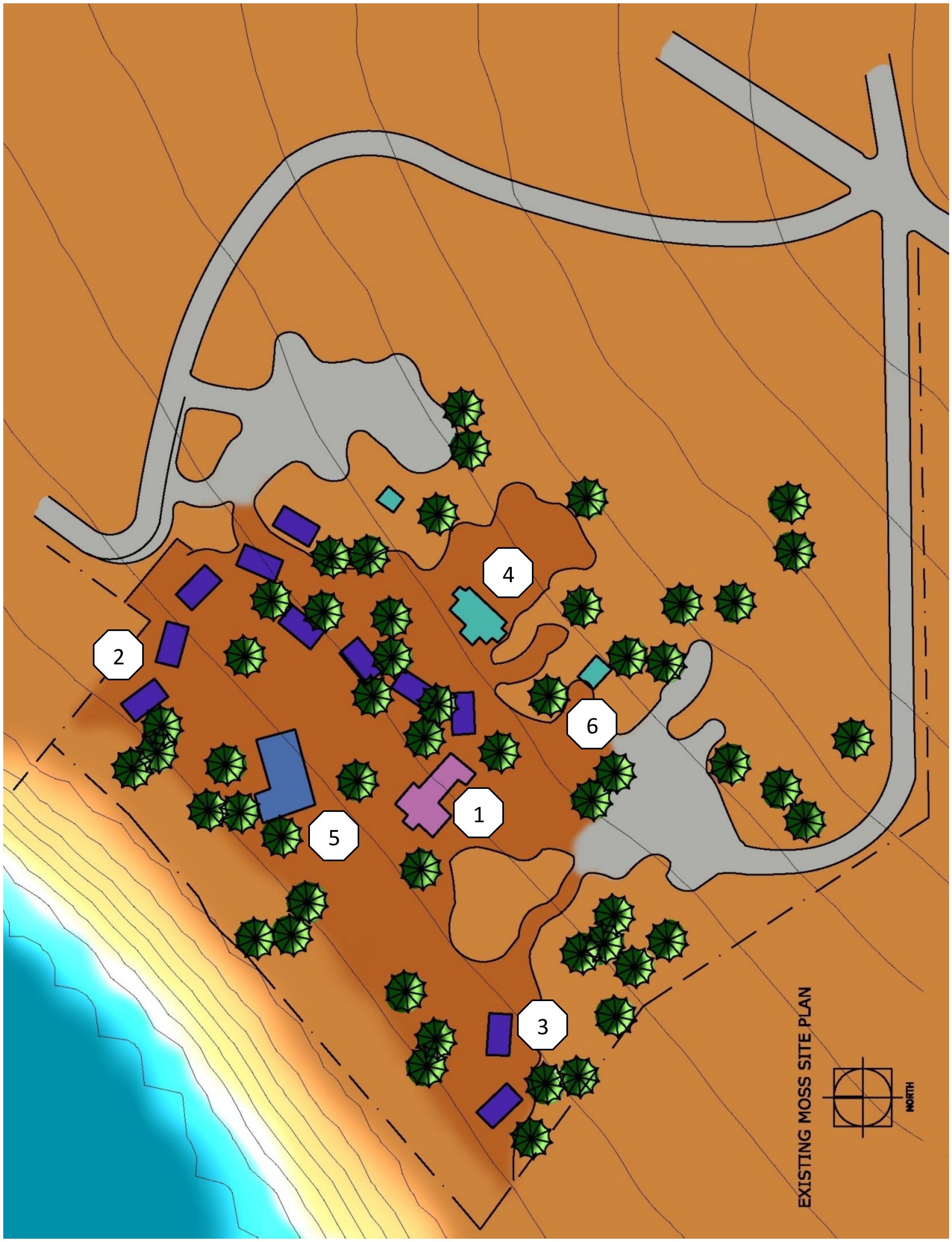
Currently, there exists on the McCall Field Campus a historic dining hall with a capacity to accommodate 70 people. There are eight duplex bunkhouses which contain twelve beds per bunkhouse with a total of 96 beds available currently for guests. There are two duplex units with a bathroom and kitchenette which contain six beds in each bunkhouse for a total of 12 beds. There are two small cabins, and two residence yurts which contain two beds per yurt. There is a centralized bath house on the premises for guests and staff. There is one shared classroom and office building which also includes an efficiency apartment, and there are also two thirty foot classroom yurts. Lastly, there also is a workshop on the campus.

1.6 This is the historic dining hall which can hold up to 70 people (MOSSIdaho.org, 2008).

1.7 This is a photo of the duplex guest bunkhouses (MOSSIdaho.org, 2008).

1.8 A photo of the interior of a bunkhouse (MOSSIdaho.org, 2008).

1.9 This is a photo of one of the classroom yurts (MOSSIdaho.org, 2008).



1.10 This is a rendered site plan of the current McCall Field Campus' building locations, property boundary, roads, and tree locations. LABELS: 1. The historic dining hall and kitchen 2. Duplex bunkhouses 3. Duplex residence units 4. centralized bath house 5. Classroom and office building 6. Workshop

Area and Environmental Information

The McCall Field Campus is zoned as “Residential Estate.” The Residential Estate land use designation permits the development of large lot, single family residential areas, and is intended to provide for a rural setting and encourage preservation of open space and recreation areas. This zone allows a maximum density of one dwelling unit per five acres (City of McCall Idaho, 2006). Despite the residential zoning of the area The McCall Field Campus, does not need to abide by the zoning regulations of the area due to the fact that it is a residential education and conference facility owned and operated by the University of Idaho's College of Natural Resources in partnership with the Palouse-Clearwater Environmental Institute.

The McCall area is characterized by mild summers and cold, wet winters. The climate of McCall is influenced by the surrounding mountains and lakes, and by the altitude and latitude of the area. Due to the surrounding mountainous terrain, the town is spared most of the cold blasts from Canada, yet warm Pacific winds sweep in to provide the upland continental climate that is characteristic of the area. The average annual snowfall in McCall is 134 inches. At McCall's altitude of 5,000 feet, snow accumulation is typically less than 48 inches due to repeated settling and thawing. Winter sports in the area generally begin in mid-November and continue through April (McCall Area Chamber of Commerce, 2008).

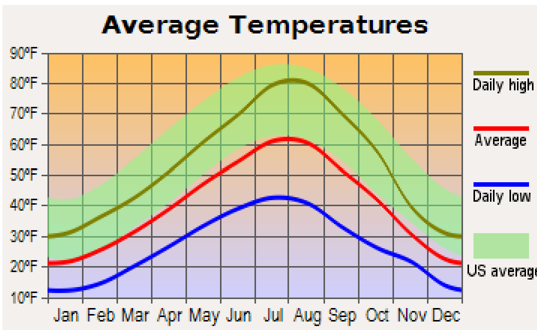
McCall's elevation is slightly over 5,000 feet and is surrounded by mountains which average 8,000-9,000 feet. A wide variety of flowers bloom abundantly in the area with very little concern about pests or diseases. The average growing season is 69 days, roughly June 16 to August 24, with temperatures rarely reaching into the 90's and nights cooling to the 40's and 50's. Serious vegetable gardeners find themselves challenged to provide protection for plants such as tomatoes which need long, warm seasons. In McCall, temperature and/or humidity can vary significantly enough, due the influence of Payette Lake, to affect the growth of some local plant species (McCall Area Chamber of Commerce, 2008).

Since 1905, weather patterns in McCall have been collected and analyzed. The average maximum temperature in January, generally the coldest month, is a mere 30.2 degrees and the low in January is 10.5 degrees. July is the warmest month in McCall and the average maximum temperature is 81.0 degrees, and the average low in July is 44.1 degrees. As previously stated, these summer low temperatures make vegetable growing difficult. On average, McCall receives 26.43 inches of precipitation. Most months receive 2.0 inches of precipitation or more except in December and January where McCall averages over 3.5 inches of precipitation. In the summer, July averages about 0.64 inches of precipitation. Throughout the winter, McCall receives on average 134.5 inches of snowfall. In December, the area receives roughly 32.1 inches of snow and 35.8 inches in January. The average snow depth is 27.0 inches in January, 33.0 inches in February, and 28.0 inches in March (Western Regional Climate Center, 2008).

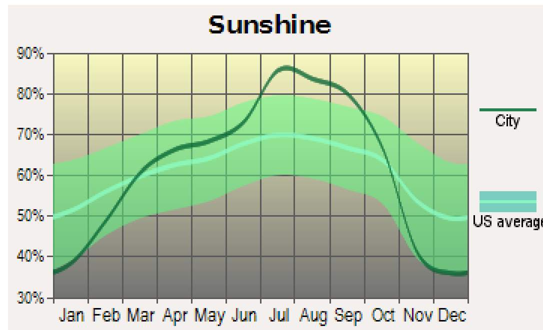
Period of Record: 05/27/1905 to 12/31/2007	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
Average Maximum Temperature (F)	30.2	35.4	41.4	50.6	61.2	69.8	81.0	79.9	70.0	57.3	40.4	31.2	54.0
Average Minimum Temperature (F)	10.5	12.5	17.8	25.7	33.5	39.6	44.1	41.7	34.8	28.0	21.7	14.0	27.0
Average Total Precipitation (in.)	3.54	2.86	2.50	1.99	2.20	1.98	0.64	0.81	1.31	1.99	2.99	3.61	26.43
Average Total Snowfall (in.)	35.8	24.3	17.8	5.6	0.8	0.1	0.0	0.0	0.1	1.9	16.0	32.1	134.5
Average Snow Depth (in.)	27	33	28	8	0	0	0	0	0	0	3	14	9

1.11 A climate data chart from May 27, 1905 to December 31, 2007 depicting the average maximum and minimum temperatures per month, the average precipitation per month, the average total snowfall per month, and the average snow depth per month in McCall Idaho (Western Regional Climate Center, 2008).

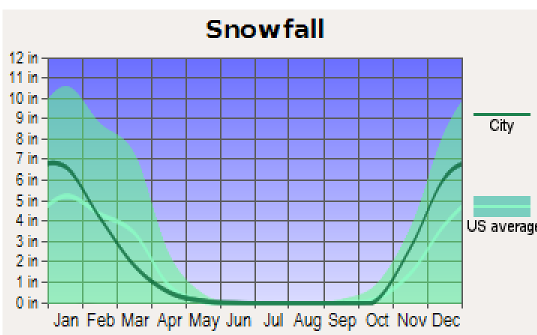
Figures 1.12-1.17 are supplemental graphs illustrating the various environmental factors which impact McCall. Figure 1.18 is a stereographic sun path diagram for latitude 45 where McCall sits. The sun rises to a maximum height of 78 degrees from the horizon in the summer on the summer solstice, and only rises to a height of 21 degrees from the horizon in the winter on the winter solstice (Luxal, 2007).



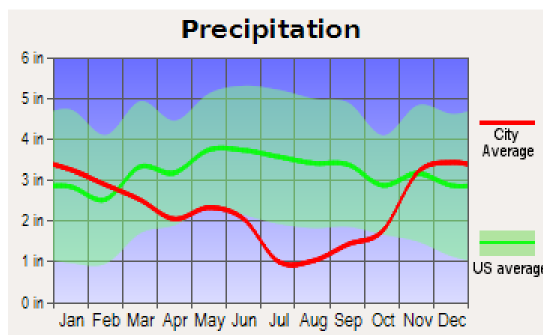
1.12 A graph of the yearly temperature averages of McCall Idaho (City-Data, 2008).



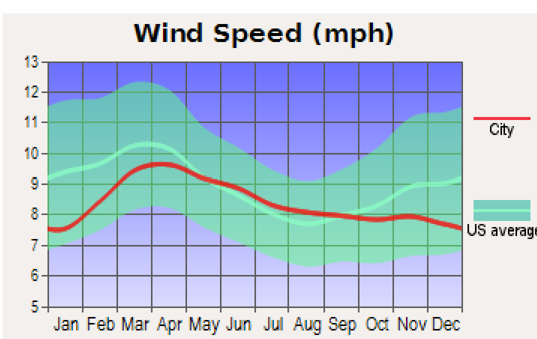
1.13 A graph depicting the average yearly amount of sunshine McCall Idaho receives (City-Data, 2008).



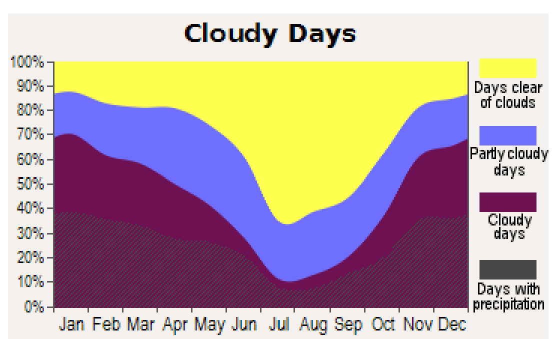
1.14 A graph depicting the average yearly snowfall that McCall Idaho receives (City-Data, 2008).



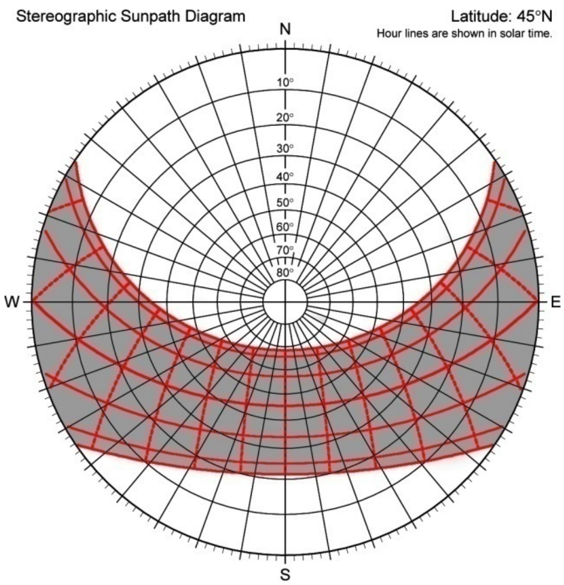
1.15 A graph depicting the average yearly precipitation McCall Idaho receives (City-Data, 2008).



1.16 A graph depicting the average yearly wind speeds McCall Idaho experiences (City-Data, 2008).



1.17 A graph illustrating the average cloudy, partial, and sunny days through the year (City-Data, 2008).



1.18 The sun path diagram of latitude 45 where McCall Idaho is located. The suns path rises to a height of approximately 78 degrees from the horizon in the height of summer at rises to a maximum of approximately 21 degrees from the horizon in the winter (Luxal, 2007).

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Chapter 2: Project Information and Definition

Description and Objective of the Project:

This “Carbon Neutral Environmental Learning Center” project seeks to capitalize on the plethora of recent advances in green technology in order to pioneer a built environment that seamlessly weaves together sustainable concepts in energy efficiency, building and finish materials, space planning and use, water treatment, and site construction with an emphasis on using the built environment as a model and teaching tool for applied sustainability. The ultimate goal is the design and construction of a Carbon Neutral Environmental Learning Center at the University of Idaho McCall Field Campus. Keen attention is to be paid to the following design components: structural systems, building envelope, environmental systems, site construction, building materials, information technology, spatial systems and integration of systems. University of Idaho graduate and undergraduate students specializing in architecture, landscape architecture, engineering, and interior design will work in interdisciplinary teams with McCall Outdoor Science School staff, industry partners and local stakeholders to plan and design and build a carbon-neutral campus. As Idaho’s only Environmental Learning Center, the resulting facilities will be uniquely poised to showcase sustainability in a state that is expected to experience a 50% rise in population in the next three decades (U.S. Bureau of the Census, Population Division, 1996) but which lacks the necessary models for sustainable growth to facilitate such an increase without compromising environmental quality. Thousands of visitors each year will participate in programs that will use the field campus’ architecture as pedagogy.

Significance/Justification of the Project:

Addressing climate change is fast becoming the highest priority of the global environmental sustainability movement. Accordingly, the United States' building sector, as the leading producer of carbon emissions and leading consumer of energy (Architecture 2030, 2006-2008), has the unique opportunity and responsibility to shape the global environmental future. When the energy used in construction materials, building usage, and maintenance of commercial and residential buildings is taken into account, the building sector accounts for almost half of the United States' energy consumption and tops the list in production of carbon emissions (Architecture 2030, 2006-2008). Failure to respond to increasing calls by top world and U.S. scientists and politicians to reverse emissions trends on a regional level will have global repercussions, the harshest consequences of which will fall on the world's poorest citizens (United Nations Development Programme, 2008). On the other hand, forward thinking building projects that are cost effective and economically viable will act as sustainable models for developing economies, compounding this project's direct environmental impact.

Idaho is a state undergoing significant change, in its economy and in its identity. Idaho's population increased by 40% from 1990 to 2005, and is now the third fastest growing state in the nation (U.S. Census Bureau, 2008). The Census Bureau projects that by 2030, population will increase by 52% to nearly 2 million (U.S. Census Bureau, 2008). By 2050, urban and suburban development is expected to double and quadruple, respectively, resulting in a loss of 4.5 million acres of ranch, farm, and open space land (FAIR Federation for American Immigration Reform, 2008). This growth will undoubtedly be accompanied by increased energy consumption. Idaho already leads the Northwest in per capita consumption (FAIR Federation for American Immigration Reform, 2008). A western state experiencing a heavy influx of people and a changing demographic is ripe for more widespread introduction of sustainable building techniques. Idaho is also one of the only states without a residential Environmental Learning Center aimed at increasing the natural resource and environmental science literacy of state schoolchildren and citizens. The process of forming an Environmental Learning Center has already begun at the University of Idaho McCall field campus through its current programming. This Carbon Neutral Environmental Learning Center project is needed to complete the process.

This project will have a direct impact on Idaho's working class. Much of Idaho's population resists the notion that environmentally positive solutions can also be good for the working class. "Environmentalism is a rich man's game. Any 'strategies' to reduce 'greenhouse emissions' in Idaho will have a harmful impact on the Idaho economy, will put immediate pressure on Idaho families by raising the cost of food, energy and transportation, and will harm the poorest Idahoans for the same reasons" (Fischer, 2008). The benefits and real applications of green technology need to be brought to the public's doorstep. Of the eleven LEED certified buildings in Idaho, the University of Idaho Environmental Learning Center will be the only public space; and the only one that takes measures to serve low-income families.

This project will serve as a resource for Idaho and for the nation. Through a close working relationship with neighboring Ponderosa State Park, the University of Idaho has been included in Ponderosa State Park plans for development of a new section of the state park, which will surround the University of Idaho McCall Field Campus. This partnership ensures that the 240,000 annual visitors to Ponderosa State Park visitors will have easy access to the University of Idaho Environmental Learning Center.

From the outset of this project, students from multiple disciplines have taken the lead in planning, designing and building this carbon neutral educational facility which will be used by thousands of people annually. Although this project begins at the university, it holds significance for education, industry, and for the region. Advances in green technologies show us that emissions reduction is possible, but application in the US building sector (Architecture 2030, 2006-2008), and especially in Idaho, is sparse. Green technologies alone have not accomplished the needed changes in building design and manufacturing. Public exposure and education is needed to establish demand for sustainable building and design practices. Industry participation is needed to establish economically viable precedents for other businesses. As Idaho's only Environmental Learning Center open to the public, the resulting facilities will be uniquely poised to showcase sustainability. Applications of sustainability will be brought to Idaho citizens through a variety of programs. The goal is to create a Carbon Neutral Environmental Learning Center in Idaho whereby just being on campus will be a unique educational experience in and of itself for designers, builders, educators, children and visitors. Advances in green technologies show us that emissions reduction is possible, but application in the United States' building sector, and especially in Idaho, is sparse. Public exposure and education is needed to establish heightened demand for sustainable building and design practices.

Project Process:

Due to the complex nature of this project, the design process first began as an interdisciplinary design studio during the 2006-2007 school year. This studio combined fifth-year architecture graduate students with fourth-year students from landscape architecture, and interior design. The project's initial participants included 36 students, 6 faculty, 5 community stakeholders and 3 industry partners. Represented were the academic disciples of architecture, landscape architecture, interior design, bioregional planning, and conservation social sciences. The community stakeholders initially involved were the McCall Outdoor Science School, Palouse-Clearwater Environmental Institute, McCall High School, City of McCall, and Idaho Department of Parks and Recreation, and the industry professionals who were involved in the project were Epikos Architecture and Land Planning, Sesech Engineering, and Southface Sustainable Construction.

During the 2006-2007 interdisciplinary design studio, the students were arranged into seven interdisciplinary teams and each team produced a master plan design. The student teams created seven distinct master plans for the site, generating a range of possibilities. Each student then took a specific building or landscape element from their team master plan to design and evaluate for feasibility, constructability, and attention to design challenges. For example, the architecture students tested their building designs in Ecotect for day lighting efficiency and to evaluate solar gains. The students also worked together on design components such as structural systems, building envelope, environmental systems, site construction, building materials, information technology, spatial systems and integration of systems.

In the 2007-2008 school year, a graduate student assistantship in architecture was assigned to a qualified and motivated student at the start of this project. This student was instrumental in mobilizing diverse resources to meet the project goals and in re-establishing a realistic timeline. One of the major goals for the project during the 2007-2008 school year was to bring together the main project collaborators in order to synthesize a cohesive master plan from the seven master plans that the students from the previous year had proposed. Although bringing so many people together from different departments and colleges was a challenge, flexibility and commitment of a diverse group was essential to the success project. During this project phase, it became apparent that further synthesis of the master plan with additional input from community stakeholders was needed before it could be finalized and the design-build phase could begin. Involvement of the community stakeholders was important in establishing infrastructure needs, viability of renewable energy possibilities, and the overall site plan design.

Two charettes were conducted to further develop the final master plan and to involve the stakeholders. A smaller team of students, faculty, industry, and community stakeholders, which formed the central design team, were responsible for synthesizing, analyzing, and developing the final plan during the Spring 2008 semester. The newly synthesized plan underwent several iterations during the course of the semester, resulting in the final proposed master plan. It is expected that when individual buildings are chosen for the design-build phase, the individual building design and placement and orientation on the master plan will be revisited. During this process, a phasing plan was developed. The phasing plan allows for transformation of the site over a longer period of time so that on-going activities at the Field Campus can be supported while new construction goes on. With the campus built in phases, University of Idaho design-build studios will have an increased role in construction over time.

During the first building phase, a showcase building will be constructed in order to demonstrate architecture as pedagogy. In the 2008-2009 school year, Frank Jacobus began conducting the first building phase of the project, as he is currently leading a group of fourth-year architecture students in a design-build studio. The goal of the studio during the Fall and Spring semesters, is to design one of the guest housing units, capable of accommodating sixteen overnight guests. In Summer 2009, the building is to be constructed on the McCall Field Campus site by the students who had participated in the 2008-2009 design-build studio. Two bunkhouses currently on the campus will be torn down to make room and the resulting material will be reused later for future graduate student housing.

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Chapter 3: Project Goals and the Master Plan

Project Design Goals:

This Carbon Neutral Environmental Learning Center project focuses on weaving together existing green technologies in planning, design and construction of an Environmental Learning Center. The overall central design challenge is carbon neutrality. It is the goal of this project that 100% of the energy will be produced onsite through renewable resources such as biomass (predominantly), solar, wind, methane, and possibly geothermal, and wave energy. Another prominent design challenge is the seamless integration of the built environment with the surrounding natural environment. This includes site specific requirements such as firewise construction to fit the region's fire dependent ecosystem and efficiency in snow shedding, removal, and storage. In conjunction with firewise construction and snow removal, slopped roofs with attached cisterns will serve well for snow storage where the water can then be stored for later use should fire occur in the area. The excess water can be utilized also for landscape irrigation or can be sent to the living machine for treatment.

The use of underutilized local materials, and recycled materials, in all facets of the project will help to reduce the overall construction carbon footprint of the project. Educational interfaces are slated to be integrated into the design of the Carbon Neutral Environmental Learning Center to highlight all sustainable design elements from energy collection/generation, to wastewater treatment, to sustainable building materials. Lastly, there is the project goal of creating this Carbon Neutral Environmental Learning Center that is cost-effective in relation to industry standards. Utilizing underutilized local materials and recycled materials will help with the project cost and so will on site power generation and collection through sustainable resources. University of Idaho design-build studios will be conducted to design and construct some of the buildings proposed in this project, the studios will negate the design cost and most of the construction cost.

Project Design Standards:

With this project, there are some design standards that have been established in conjunction with analysis of the local environment, climate, and local materials available. Specific roof design is important for this project as the roof will serve several purposes such as being firewise and snow efficient while also having a low carbon footprint. In order to satisfy these needs, the roofs designed to be incorporated into this project will have a 6:12 slope in order to adequately shed snow. The roof slope will also allow for rain water and snow to be collected in two cisterns at 1,500 gallon capacity each so that the stored water can be used for fire suppression and landscape irrigation. Overflow will go to the living machine. A “cold roof” will prevent ice damming and snow build-up. Though metal roofs are the best option for fire protection and snow shedding, the high embodied energy of steel requires use of recycled steel, which has up to 95% less embodied energy than newly manufactured steel (Mumma, 1995). The roofs are to have an insulation R-Value of R-47.5 (Westerfield, 2008). Lastly, the roofing system is to be supported by trusses, which then transfer loads to the load-bearing structural walls, which then transfers the loads to the vertical support columns.

Through careful study of the site and the surrounding area, it is understood that due to the abundance of trees and subsequent shade makes active solar unlikely to yield high levels of energy over much of the campus. In select areas photovoltaic systems can still be used for educational value and to offset energy use. Inadequate wind speeds and wind consistency (due to the mature forest setting) are unlikely to yield high-energy output but can serve to offset a small amount of energy while being used for education purposes. Luckily, the necessary amount of fuel for a biomass energy production facility can easily be provided by the nearby Ponderosa State Park, making a biomass burner a likely energy source for the learning center.

The use of underutilized, local, and recycled materials is an integral part of this project and in reducing the embodied carbon in the construction of the buildings. Preliminary embodied energy analysis shows that the reuse of the cabin materials from bunkhouses will result in an estimated 2.32 tons of saved carbon dioxide (NY Wa$teMatch, 2007). The old bunkhouse cabins are to be torn down and the materials will be reused for the future graduate and staff housing. Straw bale, rammed earth, recycled stone, and cordwood are feasible low-carbon material options. Natural ventilation in the design of the new learning center buildings and the water collection due to the roof design can be used to improve energy efficiency. Building designs that consider utilizing passive solar gain can also be effective at increasing building energy efficiency. Building orientation and window placement can optimize passive solar impact, especially in winter in which passive solar gain can be used to help warm the buildings without as much dependence relied upon electric or fossil fuel heat sources.

Proposed Green Design Elements to be Included:

There are many new technologies and advancements in sustainable/green design. In order for the Carbon Neutral Environmental Learning Center to be an example of forward thinking design and sustainability, there are many green design elements that are projected to be included into the learning center. For the majority of the learning center, recycled, salvaged, or engineered composite construction and furnishing materials are to be utilized where applicable. Untreated construction materials are to be used in order to reduce off-gassing of harmful VOCs. A central biomass power generation facility which will serve to provide both power and heat to the learning center, will utilize wood from the neighboring Ponderosa State

Park that has been harvested from the park's fuel reduction projects. Photovoltaic roof panels and wind turbines are also to be incorporated into the design of the learning center in order to demonstrate alternative energy sources while also harvesting energy.

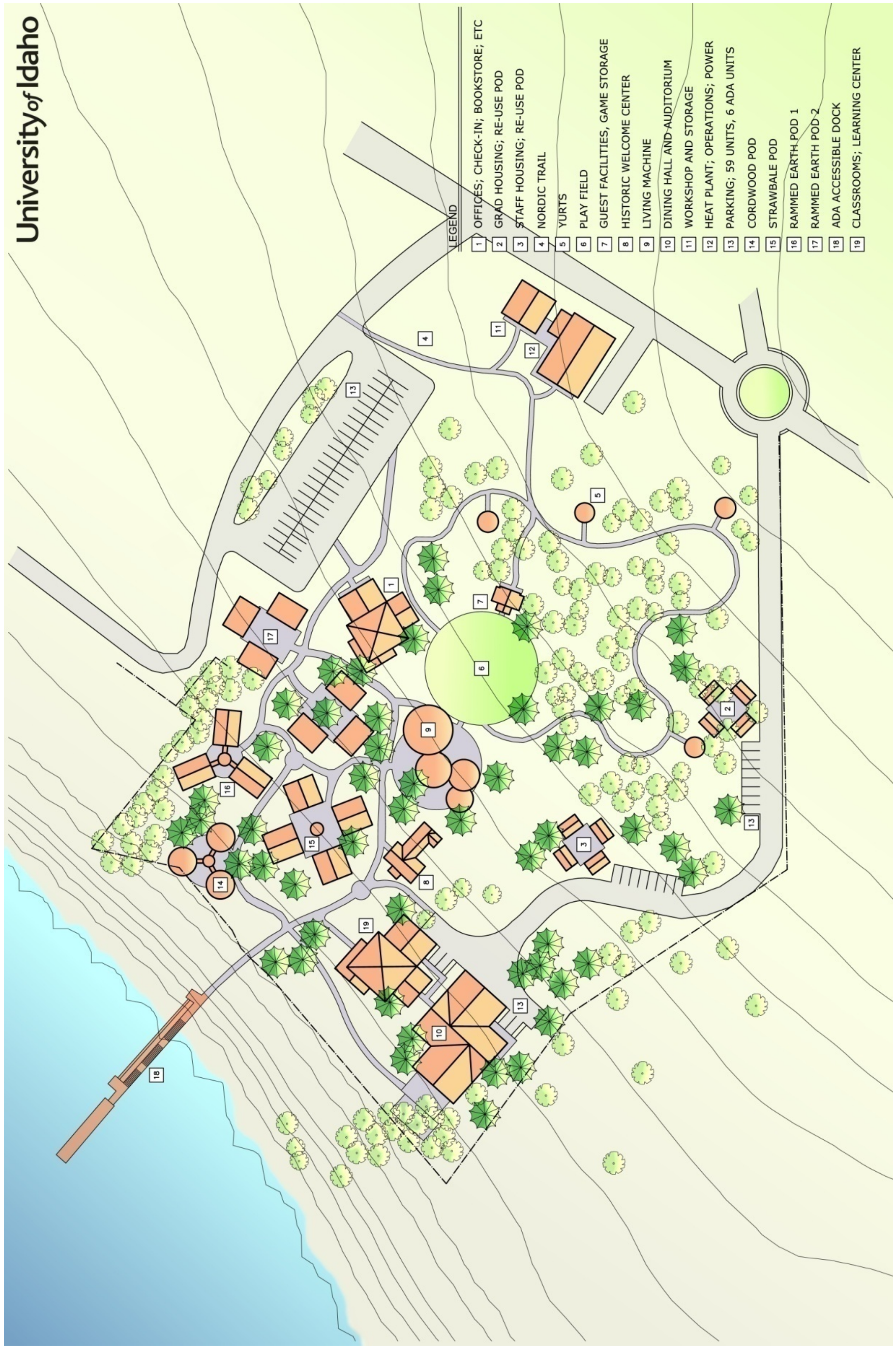
Other green design elements to be included are solar-preheated water, passive solar gain, natural ventilation design, and natural lighting design of the buildings. As discussed before, roof rainwater collection will be incorporated for several purposes such as fire suppression, landscape irrigation, and low-flush toilets. Any extra stored water can be handled by the living machine which is to be incorporated into the Carbon Neutral Environmental Learning Center for wastewater treatment. The living machine will not only serve to treat wastewater, it will also function as a significant educational opportunity for children and visitors to the learning center. Composting systems will be utilized by the learning center to recycle food and plant waste and to also serve as a significant educational opportunity. Wood products used at the learning center, if applicable, are to first be sought from the Ponderosa State Park fire repression projects. Other wood products used are to be Forest Stewardship Council (FSC) certified, locally sourced or engineered.

The learning center will use low-energy lighting, computers, and electronic equipment as well as an integrated phone, data, and video network with wireless connections. This will serve to reduce energy consumption. Lastly, interpretation interfaces and nodes which highlight the learning center's green design elements are to be incorporated. One interface that will serve as a key educational piece will be an energy interface which shows incoming energy from the various sources (biomass, solar, wind, etc.) and the energy used by the buildings (lighting, computers, and etc.) so that students and visitors can become aware of the inner workings of the energy generated and used by the learning center.

The Master Plan Program Components:

All numbers listed below are displayed in order in Figure 3.1 on the next page.

1. Visitor check-in, bookstore, five staff offices, and ten graduate studios at 2,000 ft^2.
2. Graduate student housing pod constructed from re-used (salvaged) wood. Twenty beds provided.
3. Staff housing pod constructed from re-used (salvaged) wood. Ten beds provided.
4. Educational/Nordic trail
5. Yurts with multiple uses such as staff and/or grad student housing, visitor housing, or to be used as community space, or classrooms as space needs arise.
6. Playfield
7. Guest facilities and game storage at 800 ft^2.
8. Historic welcome center (previously the historic dining hall).
9. Living machine
10. Dining hall and auditorium at 3,600 ft^2.
11. Staff workshop and storage at 1000 ft^2.
12. Biomass heat and power plant operations at 1,000 ft^2.
13. Parking; 59 units, 6 ADA units.
14. Cordwood pod, thirty beds provided.
15. Straw bale pod, thirty beds provided.
16. Rammed earth pod, thirty beds provided.
17. Rammed earth pod, thirty beds provided.
18. ADA accessible dock, 10’ x 70’ long with wind power attachments.
19. Classrooms and learning center at 2,700 ft^2; accommodates one to four flexible-space classrooms.



3.1 This is the final Master Plan that was generated through the design charettes in the Spring of 2008.

Master Plan Highlights:

The master plan is instrumental in articulating the important components and connections of the learning center. The guest cabins are arranged in pods built with different building materials to illustrate alternative building materials. The materials to be showcased tentatively include rammed earth, straw bale, and cordwood. The pod design is to facilitate a sense of community among visitors. Recycled, salvaged, or engineered, construction and furnishing materials with low volatile organic compounds (VOCs) are to be used in every building. Volatile organic compounds can be reduced by purposely choosing to leave the construction and furnishing materials in an unfinished state.

Payette Lake is the central focal element of the learning center. A line of sight is established through the center of the campus. The classroom and dining lodge, which will be the central activity areas, are located on the lake with easy access. Old growth ponderosa pines were marked and are to be retained. They are to be incorporated into a naturalist educational node. The viewshed from the lake itself will be protected by a greenbelt of vegetation and old growth ponderosa pine. Educational nodes that are to be featured at the learning center include a solar energy activity node, water systems activity node, wind and active water node, fire education/music/gathering node, construction materials activity node demonstrating the construction materials of cordwood, straw bale, rammed earth, and re-used materials, and a nature trail activity node.

A living machine greenhouse is featured at the center of campus highlighting education opportunities and increasing efficiency of wastewater treatment. Food systems education will be facilitated by the greenhouse and composting systems. A biomass power plant is to be located on the periphery of the site which is located within the Ponderosa State Park for easy offloading of collected biomass fuel. Photovoltaic roof panels are to be located on appropriate buildings which receive adequate sunlight. Wind power is to be featured by the dock on the lake, where better wind speeds persist. Educational energy center monitors will monitor and report the output from all energy sources. Passive solar gain, natural lighting, and natural ventilation design increase energy efficiency and connection to natural systems. Roof rainwater collection will be used for fire suppression, landscape irrigation, and for the living machine.

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Chapter 4: Comparative Case Studies

IslandWood, Bainbridge Island, Washington:

IslandWood is one of the nation's most innovative educational facilities, offering programs for everyone from K-12th grade children to graduate students, teachers, families, and adults. The mission of IslandWood is to provide exceptional learning experiences and to inspire lifelong environmental and community stewardship. At IslandWood, learning comes alive for people of all ages through delivering experiential "hands-on" education, using the environment as a classroom, engaging diverse learning styles, integrating science, technology and the arts, and by showcasing sustainable practices (IslandWood, 2008). IslandWood is a unique 255-acre outdoor learning center. It is an “alternative” type of school since it provides education to people of all ages. It covers 70,000 ft^2 and was completed in 2002. The facility offers programs for schools as well as programs for adults, children and families; volunteer opportunities, a speakers series, and other community events are open to the public (IslandWood, 2008).

The pioneers of IslandWood “envision a future in which all people view themselves as lifelong learners, and share an extraordinary bond of stewardship for the environment, for their communities and for each other” (IslandWood, 2008). Inspiration for IslandWood came from the land itself, and the knowledge that half of Seattle School District children did not receive overnight outdoor education programs (IslandWood, 2008). Paul and Debbi Brainerd learned in 1997 that over a thousand acres of land were being sold on the south end of Bainbridge Island. Mrs. Brainerd proposed the idea of a children’s outdoor education center to teach children about the natural and cultural history of the Puget Sound region and stewardship for the environment. At the end of 1998, 255 acres of land were purchased by the Brainerds from Port Blakely Tree Farms and then donated to the new non-profit now known as IslandWood. Then planning began in earnest as to the best way to create an educational center that could be a "magical place for kids" (IslandWood, 2008).

IslandWood is a vehicle-free campus, the natural trails that enter into IslandWood provide a pedestrian decompression zone for all visitors. Buildings are placed at northern edge of solar meadows allowing for passive and active solar systems (DesignShare, 2008). The wood that had been cleared from the solar meadows was used for the exterior siding and interior trim throughout the buildings of IslandWood. Butterfly roofs invite passive solar gain from south, active systems on north, rainwater collection, and views into the forest beyond. There is no air-conditioning at IslandWood. The building windows are operable and when they are opened, they allow the buildings to breathe and thus energy is saved (DesignShare, 2008). The building structures and systems are left uncovered, making the structural and mechanical connections visible. Materials, texture, and connections evoke layering and an interdependence of the natural systems. Siding, trim, furniture, and fixtures were crafted by local artisans from materials harvested on site. IslandWood has the largest photovoltaic array in the northwest which powers 50% of the Learning Studios classroom building. Geological fireplaces, artist-made building parts, and building energy metering provide hands-on interactive learning for students of all ages (IslandWood, 2008)(DesignShare, 2008).

IslandWood, is an active participant in energy conservation, composting, recycling, and harnessing alternative energy sources. All of the facilities of the campus feature numerous sustainable elements that help restore and maintain the site and to remind visitors that even our simple, day-to-day tasks have an impact on the environment. As children, teachers, and others visit our campus, they are quite literally surrounded by practical lessons in how to live more responsibly within the natural world (IslandWood, 2008). IslandWood received the United States Green Building Council LEED Gold rating in 2002 (DesignShare, 2008). The solar meadows and building orientations maximize passive solar gain. High performance windows optimize solar heat gain and reduce energy consumption. All concrete contains 50% flyash, a recycled utility waste product of coal. Natural ventilation replaces air conditioning. The buildings at IslandWood were designed using computer modeling to locate window openings and operable skylights for maximum air circulation. The walk-off mats at entry doors are made from recycled tires. Many building materials are left untreated to reduce off-gassing of volatile organic compounds (VOC's). Roof rainwater collected at several buildings is stored and used for landscape irrigation. More than 50% of wood products are Forest Stewardship Council (FSC) certified (IslandWood, 2008). Waste treatment is also showcased with composting toilets, a living machine, and constructed wetlands.

Process and Design:

In order to bring IslandWood to fruition, after the purchase of the property at the end of 1998, scientists and other educators were brought to the site in order to discern what educational "stories" could be taught from the land. Biologists were thrilled by the property's rich variety of ecosystems: 62 acres of wetlands, a bog, second growth forest, a stream, and access to a marine estuary in Blakely Harbor which is adjacent to the property. Cultural historians were excited by the stories of the largest mill in the world that once operated in Blakely Harbor as well as the history of the Suquamish tribe who had used the land for many years before the arrival of the white settlers (IslandWood, 2008).

Mithun Architects and The Berger Partnership worked together and designed the educational structures, trail systems and outdoor field structures with the help of children. University of Washington Landscape Architecture students worked with over 250 children in the 4th, 5th, and 6th grades in design charettes, to learn what their ideals would be for learning in the natural world. The children's ideas focused on adventure-based learning, with their design ideas generating specifics like a floating classroom, suspension bridge, forest canopy structure and several tree houses. The official groundbreaking for the center was held in the summer of 2000, construction was nearly completed in spring 2002 (IslandWood, 2008).

A detailed site and resource analysis was used to locate the buildings of the campus in areas that would cause the least impact to the most sensitive areas such as the mature forests and wetlands. As the areas were cleared for construction, all organic debris on site during the clearing and construction was reused later. Children and visitors help restore the site with native plants from an on-site nursery. IslandWood uses extensive native plantings throughout, and long-term planning for invasive species eradication. Vermiculture and "Earth Tub" composting systems are used for food and plant waste. All wastewater is treated on site using either the living machine or constructed wetlands. Both systems utilize a natural biodegradation process in which aquatic plants, microorganisms, and snails consume the organic matter and produce a highly treated effluent that can be re-used or applied safely to the surrounding soil (IslandWood, 2008).

The main center of IslandWood includes the welcome center, great hall, and administration. The small sections of carpet found in the administration office are made from 95%-recycled carpet. A 92-foot, 120-year-old salvaged wood beam serves as a major design element in the primary roof truss. The flooring is assembled from salvaged wood. Skylight and mechanically operated louvers provide solar heating and natural ventilation. The dining hall includes solar-heated water for kitchen, restrooms, and laundry operation and photovoltaic-powered fans provide for room ventilation. The bathrooms in the dining hall feature recycled glass tiles in the floor and in the wainscoting. The educational studios at IslandWood feature photovoltaic roof panels which provide electricity for 50% of lighting and electrical needs.

Composting toilets eliminate water use. An interpretive interface in the "sustainability classroom" allows students to electronically monitor their energy and water consumption. Each classroom features a different sustainable flooring such as cork, bamboo, recycled rubber, and concrete. Bathroom stall partitions are made from recycled plastic. Each classroom countertop features a different sustainable surface such as recycled-content concrete, recycled yogurt container composite, or soybean/sunflower seed bio-composite. In the creative art studio, the walls are constructed from straw bales. High-efficiency wood stoves provide an alternative heat source for the studio. Skylights and bay windows provide the classrooms with natural daylighting. In the sleeping lodges, the solar-heated water from the roofs preheats the water for the lodge's showers and sinks. The upstairs areas feature cork flooring which acts as a renewable resource and sound absorber. Throw rugs in the bunkrooms are woven from upholstery remnants and discarded clothing. Flooring in great room and loft areas are made from recycled wood. The IslandWood living machine functions as an on-site treatment system and provides tertiary treatment of wastewater. The reclaimed water is then used for low-flush toilets and as potential landscape irrigation (IslandWood, 2008).

Sustainably harvested wood was purchased and used in 75% of the entire project's construction. Site-harvested trees that had been cleared for the construction of the buildings on campus, were dried and milled, and used in the building's exterior and interior trim. Untreated plywood and oriented strand board (OSB), made from smaller trees and chips, cover the interior surfaces. Engineered lumber and trusses were utilized for the roof and floor framing thus reducing the need for large and older growth timber to be used. Engineered lumber is more resource efficient than standard lumber. Engineered lumber is composed of sawdust, fibers, chips, and small pieces of lumber. Engineered lumber performs better with less material than conventional lumber. The trusses and glue-lams used at IslandWood are also made from sustainably harvested woods (IslandWood, 2008).

IslandWood utilizes low energy computers and monitors for instructional and administrative uses. These low energy computers and monitors consume one third of the energy of most common desktop computers. IslandWood also uses an integrated phone, data, and video network with a fiber optic backbone between buildings which saves six miles of copper wire over traditional wiring techniques. Affordable and sustainable electricity production from readily available renewable resources is featured throughout the site. The renewable energy sources featured at IslandWood include wind-power at the learning studios, a micro-hydro component at Mac's Pond, and the photovoltaic panels on the classroom roofs (IslandWood, 2008).

4.1 The gardens at IslandWood. Photo by Bruce Haglund.

4.2 Photovoltaic arrays on the building roofs help to power IslandWood. Photo by Bruce Haglund.

4.3 Exterior photo of the building façade. Photo by Bruce Haglund.

4.4 The IslandWood living machine. Photo by Bruce Haglund.

4.5 The butterfly roofs drain rainwater into cisterns for water storage. Photo by Bruce Haglund.

4.6 An interior photo of a classroom at IslandWood. Photo by Bruce Haglund.

IslandWood Parallels to the Carbon Neutral Environmental Learning Center:

IslandWood is a case study of an environmental learning center that the University of Idaho and the McCall Field campus is looking to emulate in its delivery of sustainable applications to the built environment, energy, water treatment, and education. Many of the applications seen in IslandWood would work well at the Carbon Neutral Environmental Learning Center such as leaving building structures and systems uncovered making the building connections visible and to highlight materials, texture, and connections in order to evoke layering and an interdependence of the natural systems that can be easily observed. It is the goal of the Carbon Neutral Environmental Learning Center that its visitors will also be literally surrounded by practical lessons in how to live more responsibly within the natural world. All of the facilities of the field campus will also feature numerous sustainable elements that help restore and maintain the site and to remind visitors that even our simple, day-to-day tasks have an impact on the environment.

The buildings at IslandWood were designed using computer modeling to locate window openings and operable skylights for maximum air circulation. Likewise, the buildings of the Carbon Neutral Environmental Learning Center will also be carefully scrutinized through computer modeling in order to ascertain the optimal window placement and orientation. It is also planned that building windows are to be operable and when they are opened, they will allow the buildings to breathe thus saving energy from having to cool the buildings. High performance windows can also be used to optimize solar heat gain and reduce energy consumption. IslandWood utilizes low energy computers and monitors for instructional and administrative uses. Also, IslandWood also uses an integrated phone, data, and video network with a fiber optic backbone between buildings which saves six miles of copper wire over traditional wiring techniques. Likewise, it is planned to also incorporate these elements into the design of the Carbon Neutral Environmental Learning Center.

IslandWood, is an active participant in energy conservation, composting, recycling, and harnessing alternative energy sources. The renewable energy sources featured at IslandWood include wind-power at the learning studios, a micro-hydro component, and the photovoltaic solar panels on the classroom roofs. Due to the differences in locations and surrounding environmental conditions, the Carbon Neutral Environmental Learning Center is projected to utilize biomass energy as its main energy source. Solar, wind, methane, and possibly geothermal, and wave energy can be incorporated as supplemental energy sources but they are better served to be utilized as teaching tools than as alternative energy generation methods. Building energy metering, such as an interpretive interface in which allows students to electronically monitor their energy and water consumption, is also a valuable component that can be incorporated in order to provide hands-on interactive learning for students and visitors of all ages. The living machine at IslandWood functions as an on-site treatment system and provides tertiary treatment of wastewater. A living machine which serves the same uses and functions is also a main component to be incorporated into the design of the Carbon Neutral Environmental Learning Center.

Regarding the use of underutilized and recycled materials, IslandWood incorporates salvaged wood, sustainable flooring such as cork, bamboo, recycled rubber, and concrete, different sustainable surfaces such as recycled-content concrete, recycled yogurt container composite, or soybean/sunflower seed bio-composite, and rugs which are woven from upholstery remnants and discarded clothing. Likewise, similar alternative materials are slated to be incorporated into the overall design of the Carbon Neutral Environmental Learning Center. Project coordinators have even gone so far as to suggest using recycled jeans as building insulation. More than 50% of wood products used at IslandWood are Forest Stewardship Council (FSC) certified. Likewise, it is the goals that the Carbon Neutral Environmental Learning Center also uses Forest Stewardship Council (FSC) certified wood products as well as using untreated building materials to reduce off-gassing of volatile organic compounds.

Due to a difference in climate, the butterfly roofs seen at IslandWood which invite passive solar gain from south, active systems on north, and views into the forest beyond, will not be incorporated in the design of the Carbon Neutral Environmental Learning Center. Snow in McCall piles up to four feet in the winter and a butterfly roof is not a practical roof design for the region. Sloped roofs with a 6:12 pitch are favored to efficiently shed snow. There is also the climate difference of heavier rains in IslandWood's Washington location as compared to McCall. At IslandWood, the roof rainwater is collected at several buildings and is stored and used for landscape irrigation. As for the Carbon Neutral Environmental Learning Center, it is imperative to shed snow and rain from the roofs and to collect it into cisterns with a 1,500 gallon capacity each, to be used for fire suppression and landscaping. Overflow will be diverted to the living machine for treatment.

BedZED, the Beddington Zero Energy Development:

BedZED is the largest eco-village in the United Kingdom. It is a Peabody Trust development in partnership with BioRegional and was designed by Bill Dunster Architects (Organ, 2002). In early 1999, the Peabody Trust appointed Arup as part of the design team for the Beddington Zero (fossil) Energy Development, better known as BedZED. Peabody, one of the largest housing associations in London, is a long-established and forward-thinking social housing provider. "BedZED was conceived to show that in large-scale construction, a high level of sustainability can be both practical and cost-effective. If the sustainability concept is to have any sort of meaningful overall effect on the environment, it must move into the volume mainstream, satisfy economic and social objectives, and benefit all stakeholders" (Twinn, 2003).

The design of BedZED was the culmination of many years of idea testing between Arup and architect Bill Dunster. Many of the debates and discussions revolved around fully harnessing renewable natural resources, achieving closed-loop material use, site resource autonomy, social involvement, and how all of these topics could respond to ever-increasing lifestyle expectations (Twinn, 2003). BedZED offers 99 homes, most of which were occupied by September 2002, and has workspace for around 100 people. The housing is arranged in five terraces, all of which face south and have triple storey conservatories to maximize light and warmth from the sun. BedZED's outer walls and roofs are super-insulated, combined with triple glazed windows; this negates the need for a central heating system. A wind powered heat exchanging ventilation system keeps the homes supplied with fresh air at near room temperature (Organ, 2002). As the first development of its kind, BedZED did suffer from cost over-run, but when the areas of risk became defined, BioRegional worked with construction companies to reduce costs. The BioRegional Development Group works with other architects to interpret sustainable living into different styles, broadening the audience that is receptive to adopting green living (Organ, 2002).

BedZED boasts of a reduced environmental impact where zero fossil fuel, 100% of the energy used is renewable energy, the homes require zero heating because they utilize passive solar heating. Energy is predominantly generated by the urban tree waste bio-fuelled combined heat and power plant. Photovoltaic power could be used to power up to forty electric vehicles, although currently there are only two electric vehicles on site. There is on-site ecological water treatment, and BedZED boasts of a 50% reduction in potable water use. BedZED uses wind-powered ventilation systems, low embodied energy materials, recycled timber, and reused structural steel. There are bike facilities, recycling facilities, sunlight and daylight amenity, air quality and comfort was considered and included in the design of the buildings and spaces. There is also a reduced need for car because BedZED offers a local car pool amenity (Twinn, 2003)and it is located in close proximity to transit and train.

The buildings of BedZED are largely constructed from recycled, reclaimed, environmentally accredited and local materials. For example, the structural steel which was used was reclaimed from a building in Brighton. Recycled, reclaimed, environmentally accredited and local materials are low impact materials which served to reduce the site's embodied impact by 20-30% (Organ, 2002). The largest environmental savings in terms of CO_2 reductions come from BedZED's green lifestyle features such as the green transport plan which includes a car club. BedZED promotes walking, cycling and the use of good local public transport and combined with the green transport plan, has given BedZED an 11% reduction of CO_2. Local food links help residents reduce their CO_2 by 4% and waste recycling reduces carbon impact by a further 3%. The architectural carbon savings are less significant with only a 1% CO_2 reduction from the south facing conservatories and another 1% reduction from the solar panels (Organ, 2002).

The earliest concepts for BedZED centered on the idea of home energy autonomy, with each dwelling operating solely on the ambient energy it could harvest from the sun. This led to the energy-consuming systems in the dwelling units being reduced enough to match the energy harvested from solar photovoltaic panels, thermal collectors, and a small wind turbine. Unfortunately, in cost terms this was not viable option. An alternate solution was sought and so the thinking turned to wider local community autonomy, eventually identifying a bio-fuelled combined heat and power plant as the solution (Twinn, 2003). Photovoltaic panels provide a supplemental source of renewable energy. Kitchens and bathrooms are fitted with the latest energy saving appliances. Monitoring data on water and energy consumption has demonstrated a savings of over 30% on water use from water efficient appliances and fittings alone and approximately 90% on space heating (Organ, 2002).

BedZED utilizes a 130 kilowatt combined heat and power plant which meets most of the energy demands at BedZED (Sommerhoff, 2003). The combined heat and power plant is fuelled by woodchips from waste timber that would otherwise be sent to landfill (Organ, 2002). A key element of sustainability and its resource productivity is finding waste streams and using them as raw materials. An existing local community waste stream was identified in the form of urban tree waste. Tree prunings had previously been consigned to the landfill by the local authority, but the increasing landfill tax made the tree prunings an ideal alternative low cost energy source**.** Its origin from trees also gave renewable credentials to this waste, with the carbon emitted from combustion being re-absorbed by the continued tree growth (Twinn, 2003).

Clean water is increasingly seen as a finite natural resource even in the United Kingdom. Increasing water demand highlights the capabilities needed to deliver clean water without waste and then transport and treat the resulting discharges. BedZED sought to reduce treated potable water demand by more than 50% and then treat the effluent on site. Various good practice measures have been incorporated, including restrictors to prevent excess water flows, metered pressure showers, water meters visible to consumers, minimal water-consuming appliances, and very low/dual flush toilets. Rainwater is collected from roof surfaces and stored in underground tanks for irrigation and toilet flushing (Twinn, 2003). An ecological on-site foul water treatment system, better known as a living machine, was added to the development after a statutory water authority agreed that it would adopt and operate the completed water treatment system. The living machine uses vegetation as a cleaning agent in the secondary and tertiary treatment stages, partly because of its low energy consumption. The system treats the water to a high enough standard for it to feed the recycled 'green water' into the rainwater storage tanks for later use (Twinn, 2003). The surface water runoff is handled using sustainable drainage system principles for surfaces where there may be slight contamination by cars, animals, or garden treatments. At BedZED, the use of permeable surfaces, foundation filter media for cleaning any contamination, and site water holding features, avoids draining surface water into the local sewers. Instead, the rainwater slowly percolates into the ground and into local watercourses, as would be the case had there been no buildings on the site (Twinn, 2003).

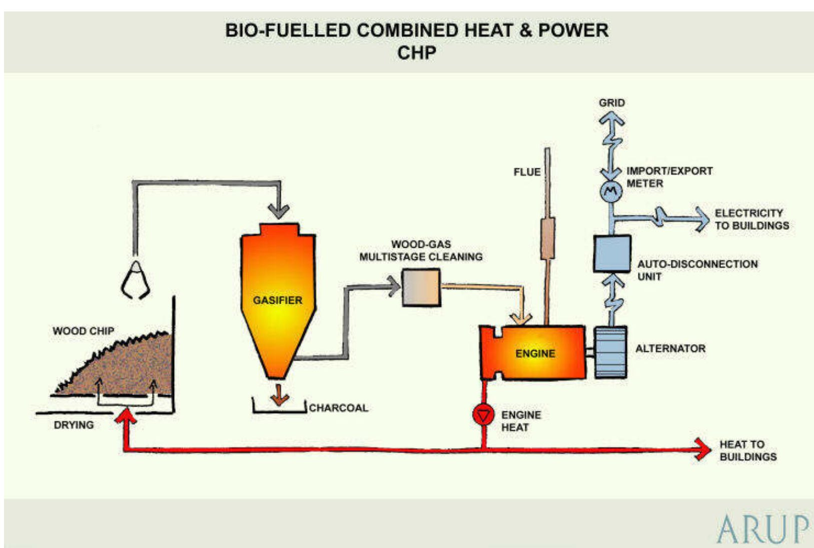
As of today, locating reused and secondary material sources, verifying their origin, and guaranteeing their performance, is difficult and requires significant manpower resources. On previous projects with Dunster, almost 80% use of secondary materials had been achieved, but limited time and cost meant more modest levels at BedZED. Most existing site material was retained at the BedZED location, whilst much of the heavier building materials were procured from within a 55km radius to reduce transport impact and allow for checking of the material origin. Salvaged structural steel was used in the workspace framing structure, and reclaimed timber for internal partition studwork (Twinn, 2003). Materials with a recognized environmental standard, like Forest Stewardship Council (FSC) certified wood, were used extensively. Kitchens units are made of plywood from a verified source, instead of the chipboard that would be typically used. Waste was addressed both at construction and for the lifetime of the buildings. Building waste was segregated on site and sent for recycling. For the homes, a domestic segregation strategy was agreed upon with the local authority, with segregation bins provided in all kitchens and around the site for local authority collection. There is on-site processing of green waste. Identifying and recording the full extent of the building materials' environmental impact and the amount of consumer waste recycled forms part of an on-going research program (Twinn, 2003).

4.7 Exterior photo of the BedZED building façade. Photo by Bruce Haglund.

4.8 Exterior photo of the BedZED building façade. Photo by Bruce Haglund.

4.9 The living machine uses vegetation to treat waste water. Photo by Bruce Haglund.

4.10 Sunlit porches face south and help to warm the living units. Photo by Bruce Haglund.



4.11 The CHP system burns bio-fuel to provide electricity, hot water, and backup heat to BedZED. Diagram by ARUP.

BedZED Parallels to the Carbon Neutral Environmental Learning Center:

BedZED is a case study of a “zero (fossil) energy” living development that the University of Idaho and the McCall Field campus is looking to emulate in its delivery of sustainable applications to the built environment, energy, and water savings and treatment. Many of the applications seen in BedZED would work well at the Carbon Neutral Environmental Learning Center such as BedZED’s demonstration that even in large-scale construction, a high level of sustainability can be both practical and cost-effective, the use of 100% renewable energy, the use of low embodied energy materials, recycled timber, and reused structural steel, monitoring data on water and energy consumption helps track energy and water use, the collection of rainwater, and the use of vegetation as a cleaning agent in the secondary and tertiary treatment stages of effluent water. It is the goal of the Carbon Neutral Environmental Learning Center that its visitors will also be literally surrounded by practical lessons in how the built environment can coexist responsibly with the natural world.

If the sustainability concept is to have any sort of meaningful overall effect on the environment, it must be brought into the mainstream, it must satisfy economic and social objectives, and it must benefit all stakeholders (Twinn, 2003).This is why since the beginning of the project, in order to bring sustainability to the people and children of Idaho, the University of Idaho and the McCall Field campus, the local stakeholders of the Carbon Neutral Environmental Learning Center project were sought out and asked for their participation. The participants who brought BedZED into reality, thought carefully about cost and found ways to create a project that was cost-effective. Fortunately, the McCall Field campus, which is the site of the Carbon Neutral Environmental Learning Center, has the benefit of being leased from the State of Idaho and operated by the University of Idaho’s College of Natural Resources and it is also located within the Ponderosa State park. Both of these entities can offer resources at little to no cost.

The University of Idaho's Architecture Department is conducting design-build studios where students design and build one building at a time. This means that there are negligible design costs for the buildings designed and constructed in this fashion. Because the McCall field campus is located within the Ponderosa State park, resources such as wood for fuel and building material can easily be procured through the state park.

BedZED boasts of a reduced environmental impact where the facility uses zero fossil fuel, 100% of the energy used is renewable energy. Energy is predominantly generated by the urban tree waste bio-fuelled combined heat and power plant. A key element of sustainability and its resource productivity is finding waste streams and using them as raw materials. Likewise, the Carbon Neutral Environmental Learning Center will utilize a bio-fuelled combined heat and power plant which is fuelled by wood waste from the Ponderosa State Park. The wood waste generated by the Ponderosa State Park is due to the park's fire management regime and is generally burned in slash piles in the forest. The origin of biomass from trees also gives it credentials as a renewable energy resource. Also, the carbon emitted from combustion of the biomass is re-absorbed by the continued tree growth within the state park. At BedZED, photovoltaic power is used to power electric vehicles. The learning center will also enlist photovoltaic power, but due to the environmental factors, solar power is unlikely to yield high amounts of energy and will therefore serve as a supplemental energy source to the biomass energy facility. At BedZED, the homes require zero heating because they utilize passive solar heating and super insulation. This scenario of zero-heating in McCall is highly unlikely due to the variations in sun angles, vegetation shade, snow buildup, and cold climate. Passive solar gain is expected to be an integral part of the building designs at the learning center through careful window location, thermal mass, and high building insulation values, though some heating demand is still expected and will be provided by the on-site biomass facility.

BedZED uses wind-powered ventilation systems, low embodied energy materials, recycled timber, and reused structural steel. The buildings of BedZED are largely constructed from recycled, reclaimed, environmentally accredited and local materials. Recycled, reclaimed, environmentally accredited and local materials are low impact materials which served to reduce the site's embodied impact by 20-30% (Organ, 2002). Materials with a recognized environmental standard, like Forest Stewardship Council (FSC) certified wood, were used extensively at BedZED. For the Carbon Neutral Environmental Learning Center, the extensive use of low embodied energy materials, and recycled or reused materials is being researched. It is also a goal to utilize local underutilized materials such as cordwood from the Ponderosa State Park. It is still unknown how much of an embodied carbon savings that can be achieved by the learning center, but by looking at the local resources available and the carbon costs of different materials, we can ascertain an approximation and make suggestions as to the best materials to use.

BedZED sought to reduce treated potable water demand by more than 50% and then treat the effluent on site. At BedZED, there is on-site ecological water treatment. The on-site ecological water treatment uses vegetation as a cleaning agent in the secondary and tertiary treatment stages. The system treats the water to a high enough standard for it to feed recycled 'green water' as a supplementary feed into the rainwater storage tanks (Twinn, 2003). In order to reduce the water consumption demand by half, various good practice measures had been incorporated, including restrictors to prevent excess water flows, metered pressure showers, water meters visible to consumers, minimal water-consuming appliances, and very low/dual flush toilets. Likewise at the Carbon Neutral Environmental Learning Center, it is projected that water efficient appliances will be incorporated, potentially including composting toilets as seen at IslandWood, which require no water. Effluent water will be treated at the proposed living machine at the learning center which will also use vegetation as a cleaning agent in the secondary and tertiary treatment stages. The living machine is not only meant to treat waste water, it is meant to function as a learning node for children and other visitors. At BedZED, rainwater is collected from roof surfaces and stored in underground tanks for irrigation and toilet flushing. Likewise, mostly through roof design, rainwater and snowmelt will be captured into cisterns and stored for later uses such as fire suppression and landscape irrigation. At the learning center, the only impermeable surfaces are slated to be the buildings themselves which will shed water and snowmelt into storage tanks for later use. Some walkways may need to be constructed from concrete due to climate and ADA egress regulations, and these walkways will also be impermeable, though they will make up little of the overall site's landscape surface. Driveways and parking lots are currently unpaved, and may likely remain unpaved.

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Chapter 5: Feasibility Assessment of a Biomass Power Facility

Study Introduction:

Addressing climate change is fast becoming the highest priority of the global environmental sustainability movement. Changes in climate reflect variations within the Earth's atmosphere, the processes in other parts of the Earth such as the oceans and ice caps, and changes in climate also reflect the effects of human activity on the Earth (Intergovernmental Panel on Climate Change, 2007). The biggest anthropogenic factor of present concern is the increase in CO_2 levels due to emissions from fossil fuel combustion (Intergovernmental Panel on Climate Change, 2007). Other factors, including land use, ozone depletion, animal agriculture, and deforestation, also affect climate (Intergovernmental Panel on Climate Change, 2007). In recent years, humanity has sought ways to slow or reverse the impacts that CO_2 emissions are having on the climate. One way to curb the CO_2 emissions of fossil fuels is to stop using them and find alternative sources of carbon neutral, renewable energy.

Biomass is an excellent form of renewable energy (Singh, 2008). Renewable energy refers to fuel sources more consistently available than their fossilized counterparts (Singh, 2008). If biomass is harvested at a rate that is sustainable, using it for energy purposes does not result in a net increase in atmospheric carbon dioxide (Yemshanov, 2008) (Twinn, 2003). Among several sources capable of supplying large amounts of carbon neutral energy, such as solar, hydro, wind, and geothermal, biomass ranks as one of the few options already competitive in some markets (Demirbas, A., 2004). It is a low cost, renewable fuel (Grahn, 2007).

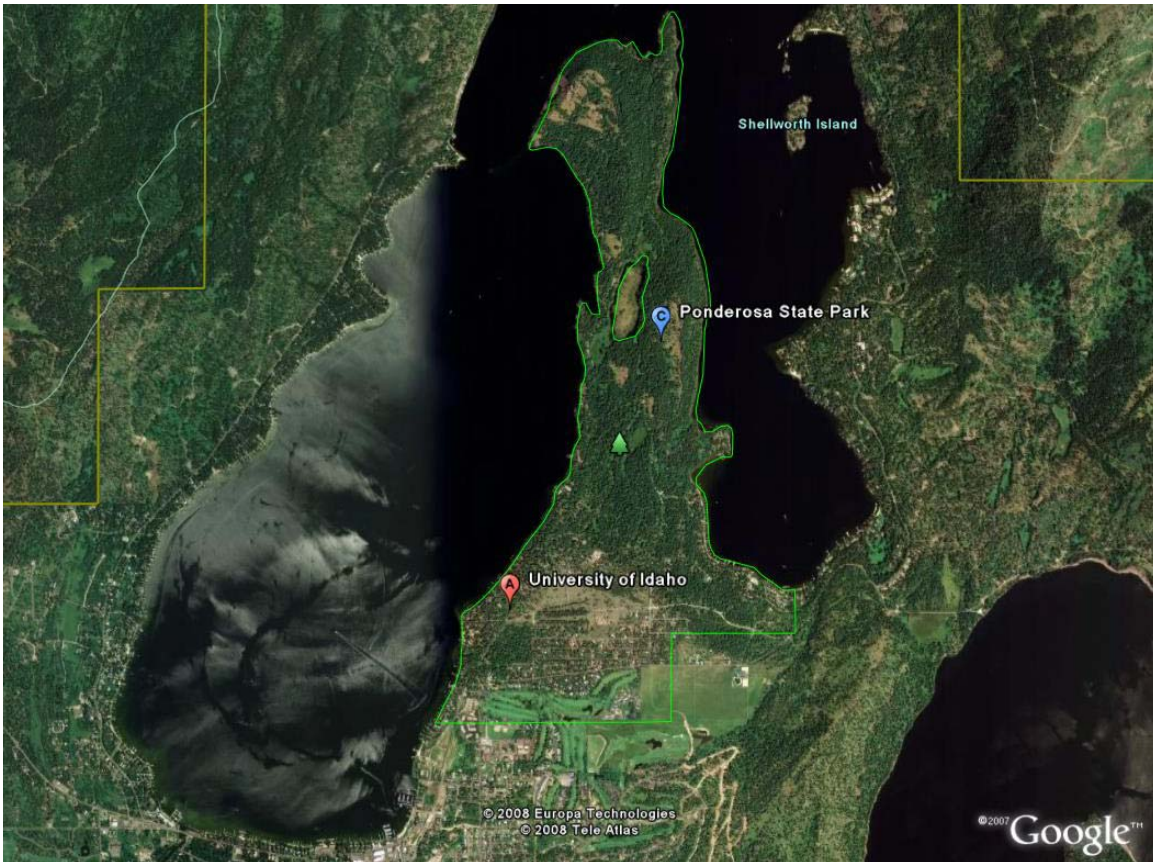
Another way that humanity is addressing the problems of climate change is through rethinking and redesigning the built environment. Forward thinking building projects will act as sustainable models for future development of the built environment. The University of Idaho is attempting to meet the challenge of developing sustainable building models. The ultimate goal of the University of Idaho's College of Natural Resources, College of Art and Architecture, and McCall Outdoor Science School's collaborative partnership, is the design and construction of a Carbon Neutral Environmental Learning Center at the University of Idaho's McCall Field Campus. Thousands of visitors each year will participate in programs that use the Environmental Learning Center's architecture as pedagogy. The scope of this assessment is to focus on the utilization of carbon neutral alternative energy sources, namely biomass, harvested from the Ponderosa State Park, to be used as fuel to generate the energy necessary to sustain the Environmental Learning Center.

Methods and Data:

The goal of this feasibility assessment is to first identify the project location and its relationship to the Ponderosa State Park. The second goal is to identify the Ponderosa State Park as the main source of biomass for the Environmental Learning Center. Third, there is a need to identify the amounts of biomass set forth by the Park's Natural Resource Plan and park manager, Dennis Coyle, which can be harvested from the forest. Fourth, calculate the current energy usage of the McCall Outdoor Science School and the equivalent carbon footprint of the campus in its energy needs. Fifth, calculate the amount of biomass needed to be harvested on a monthly and yearly basis from the Ponderosa State Park. Sixth, calculate the carbon emission equivalent produced or saved through the utilization of biomass. Seventh, and lastly, define an average distance radius from the McCall Outdoor Science School to biomass harvest locations and then calculate the carbon costs for transporting the biomass needed to supply the campus's energy demands.

Study Location:

The University of Idaho McCall Outdoor Science School field campus is located on Payette Lake within the Ponderosa State Park, in McCall Idaho [See photograph 5.1]. The Ponderosa State park consists of the Payette Lake peninsula which is approximately 3.0 miles in length by 0.5 miles in width, and the perimeter of the peninsula is approximately 10.0 miles (Google Earth, 2008) which encompasses an estimated 1,000 acres of land. The Ponderosa State Park also manages some property on the North Beach of Payette Lake which encompasses approximately 490 acres (Coyle, 2008) of land which is approximately a 7.0 mile drive around the east side of the lake from the McCall Outdoor Science School, and a 9.5 mile drive around the west side of the lake from the McCall Outdoor Science School [See figure 5.1]. These acreage and distance figures will be important later for quantity analysis, carbon analysis, and biomass transportation analysis.



5.1 Location of the University of Idaho McCall Outdoor Science School field campus, marked as the red balloon "A", and the location and boundary line of the Ponderosa State Park, marked as the blue balloon "C" and the green boundary line around the peninsula (Google Earth, 2008).

The Ponderosa State Park:

The Ponderosa State Park has a history dating back to 1905, when the Boise Columbian Club sponsored a bill to protect the wooded peninsula on Payette Lake. Resource management and public safety requires the Ponderosa State Park staff to control fire, both natural and human caused (Ponderosa State Park, 2003). The potential for major destruction from a catastrophic wildfire in Ponderosa State park is high (Thaxton, 2006). Many areas within the park have heavy fuel loading created by wind throw or trees that have been/are infected or killed by insects and diseases. The removal of fuels may require the use of piling, thinning and prescribed burns to reduce fuel loading and fuel ladders (Ponderosa State Park, 2003). Approximately 35% of the park is rated high in fire potential, 55% moderate fire potential and another 10% as low fire potential (Ponderosa State Park, 2003). The high fire potential areas encompass an area that may endanger life and property (Ponderosa State Park, 2003).

According to Ponderosa State Park manager Dennis Coyle, currently there is no market for the utilization of the harvested fuel and consequently it is typically burned onsite or hauled to a larger slash pile near the park shop headquarters. Another issue that the Ponderosa State Park faces is that there currently is not a market for timber either. Thus, The Ponderosa State Park cannot sell trees to generate the money to do the pre-commercial thinning necessary (Coyle, 2008). This is where the University of Idaho and the McCall Outdoor Science School wishes to step in. If the Ponderosa State Park collaborates with the University of Idaho and the McCall Outdoor Science School, then the Ponderosa State Park could sell their slash, timber, and trees to the Environmental Learning Center for use in a biomass power plant. This would create a collaborative partnership between the University of Idaho and its Environmental Learning Center, and the Ponderosa State Park. The Ponderosa State Parks fire management plans could be funded and implemented as necessary; meanwhile the McCall Outdoor Science School's Environmental Learning Center will have a cheap, renewable, and essentially carbon neutral, fuel supply for power generation. According to Mr. Coyle there is theoretically enough fuel that could be generated for 5 to10 years to supply most of the McCall Outdoor Science School's Environmental Learning Center's needs (Coyle, 2008). As it stands currently, the Ponderosa State Park will not be doing any large scale timber management until the market improves or funding becomes available to off-set the cost of the fire management efforts (Ponderosa State Park, 2003).

Collection of Fuel:

Fuel from fire management restoration efforts is generally piled on site or hauled by park staff to a larger slash pile near the park shop headquarters. In times when there is not a timber project, the parks fire management efforts generate a pile of biomass fuel approximately 25’ by 50’ (Coyle, 2008). According to the Idaho Department of Lands, the Ponderosa State Park can generate 5.77 tons of slash per million board feet of harvested timber. On non-commercial thinning projects, 10.5 tons of slash per acre are generated (Coyle, 2008). These figures are estimated from harvested trees less than 8” in diameter (Ponderosa State Park, 2003).Typically, fuel is hauled ½ ton, to 1 ton at a time (Coyle, 2008).

The Current McCall Outdoor Science School Energy Use:

The McCall Outdoor Science School utilizes both electricity and propane for its energy and heating needs. Records of the campus’s monthly electricity and propane usages were obtained from the University of Idaho College of Natural Recourses office where all records of the McCall Outdoor Science School expenses are compiled and stored. The analyses are based on the most recent year’s energy usage information from April 2007 through March 2008.

The yearly propane usage which was given in gallons per month, was converted to the equivalent kWh of energy per month by multiplying the gallons used per month, by the energy conversion factor of 90.0054 kbtu/gallon. This was then divided by the energy conversion factor of 3.412 kbtu/kWh (Energy Star, Energy Unit Converstion Table, 2008) Next an analysis of the equivalent lbs of CO_2 emissions generated per month was calculated using the conversion factor of 12.669 lbs/gallon (Energy Information Administration, 2008) [See Table 5.2]. The yearly electricity usage, which was given in kWh per month, was analyzed for the equivalent lbs of CO_2 emissions generated per month using the conversion factor of 0.03 lbs/kWh (Energy Information

Administration, 2008) [See Table 5.3]. The conversion factor for the equivalent lbs of CO_2 emissions generated per month through the use of electricity is assuming that the electricity is being supplied by a coal powered electricity grid.

Table 5.2- Propane usage, equivalent kWh, and CO_2 Emissions			
	Gallons/Month	**Total kWh/Month**	**Total CO_2 lbs/Month**
Apr-07	1,440.15	37,989.82	18,245.26
May-07	1,151.30	30,370.23	14,585.82
Jun-07	601.35	15,862.92	7,618.44
Jul-07	449.50	11,857.26	5,694.65
Aug-07	540.30	14,252.61	6,845.06
Sep-07	358.69	9,461.91	4,544.24
Oct-07	844.00	22,263.94	10,692.64
Nov-07	2,264.20	59,727.50	28,685.15
Dec-07	1,245.10	32,844.58	15,774.17
Jan-08	1,118.00	29,491.80	14,163.94
Feb-08	1,762.30	46,487.84	22,326.58
Mar-08	1,754.65	46,286.04	22,229.66
Total per Year	**13,529.53**	**356,896.47**	**171,405.62**

Table 5.3- Electricity usage and equivalent CO_2 emissions		
	kWh/Month	**Total CO_2^-lbs/Month**
Apr-07	11,883.00	356.49
May-07	11,535.10	346.05
Jun-07	10,932.00	327.96
Jul-07	10,623.70	318.71
Aug-07	13,206.00	396.18
Sep-07	11,655.00	349.65
Oct-07	12,254.30	367.63
Nov-07	16,029.00	480.87
Dec-07	14,911.00	447.33
Jan-08	15,174.50	455.24
Feb-08	20,218.80	606.56
Mar-08	19,210.70	576.32
Total per Year	**167,633.10**	**5,028.99**

The Current McCall Outdoor Science School Energy Use Results:

The University of Idaho's current McCall field campus uses approximately 167,633 kWh in electricity and 13,530 gallons of propane in year-round operation; totaling in 524,529.57 kWh or 524.5 MWh, of total energy needed per year. The campus also generates an estimated average of 176,434.61 lbs of CO_2 every year through their electricity and propane usages [See Tables 5.2 and 5.3]. It was important to conduct a monthly energy analysis since energy demands are variable depending on climate temperature. It is clear from the results that energy demand is highest in winter between November through April with a slight energy demand dip during the December to January holiday season when the campus is closed to public operations. The energy increase is most likely due to the cold winter temperatures which facilitate a higher demand for heating. The days in winter are also significantly shorter, which also facilitates a higher demand for lighting.

The Amount of Biomass Needed to be Harvested:

By adding together the electricity and propane kWh of energy needed per month, it was possible to ascertain the total energy needed on a monthly and overall yearly basis. With this information, it is possible to estimate the amount of biomass needed to supply the necessary kWh of energy through this equation:

$$\mathbf{E = (1/3.6)\ \eta\phi\ DB}$$

Where E is the amount of electricity generated (MWh), or in this case needed to be produced; D is the density of dry woody biomass ($t\ m^{-3}$); B is the volume of logging residues or biomass/fuel in this case (m^3); ϕ is the energy content of dry woody biomass ($GJ\ t^{-1}$); and η the efficiency of power conversion from biomass to electricity (Gan, J. and Smith, C. T., 2006). The density of woody biomass was and average based off Ponderosa Pine ($0.416tm^{-3}$) and Douglas Fir

(0.473tm^{-3}) which equates D as the equivalent of (0.4445tm^{-3}) (Gan, J. and Smith, C. T., 2006). The energy content of woody biomass was postulated at 19.19 GJ t^{-1} (Yemshanov, 2008) (Gan, J. and Smith, C. T., 2007) and the boiler efficiency of power conversion from biomass to electricity was estimated to be 70% (Edwards-Knox School).

Utilizing the equation above it is possible to find the volume (m^3) of biomass needed daily to supply such energy demands, from there it will be possible to then find the average volume (m^3) of biomass needed per month, and thus giving the overall yearly total of biomass volume needed to adequately supply the year round energy demands of the campus [See Table 5.4].

Table 5.4- Volume of biomass needed to supply the total energy demands

	Total MWh/Month	**Volume (m^3)/Month needed**
Apr-07	49.87	30.07
May-07	41.91	25.27
Jun-07	26.79	16.16
Jul-07	22.48	13.55
Aug-07	27.46	16.56
Sep-07	21.12	12.73
Oct-07	34.52	20.81
Nov-07	75.76	45.67
Dec-07	47.76	28.79
Jan-08	44.67	26.93
Feb-08	66.71	40.22
Mar-08	65.50	39.49
Total per Year	**524.53**	**316.25**

Using the assumptions and known variables below, and given the total volume needed per year, it was possible to calculate the total acres needed to be harvested per month that would need to be non-commercially thinned to completely provide necessary amount of volume. Likewise, it was possible to calculate the equivalent million board-feet per month that would need to be generated from commercial thinning projects to completely provide the same amount of energy [See Table 5.5].

Assumptions/Known Variables:

- 1 (bone dry) ton of softwood timber is equal to a volume of 2.4067 m^3 (Wood Products Weights and Measures).
- 1 thousand board-feet (tbf) is equal to 2.8 cords (Wood and Log Volume Conversion Factors Southern Averages., 1008).
- 1 cord is equal to 135 post of harvested timber (Wood and Log Volume Conversion Factors Southern Averages., 1008).
- There are 1,490 total acres within the Ponderosa State Park (Coyle, 2008).
- 10.5 tons of biomass fuel can be generated from 1 acre of non-commercial thinning projects (Coyle, 2008).
- 5.77 tons of biomass fuel can be generated per 1 million board-feet (Mbf) of commercial timber projects (Coyle, 2008).

Table 5.5- Volume of biomass needed: Equivalent biomass amounts harvested through commercial and non-commercial thinning methods.

	Volume (m^3)/Month needed	**Acres/Month to be thinned**	**Mbf/Month to be harvested**
Apr-07	30.07	1.19	2.17
May-07	25.27	1.00	1.82
Jun-07	16.16	0.64	1.16
Jul-07	13.55	0.54	0.98
Aug-07	16.56	0.66	1.19
Sep-07	12.73	0.50	0.92
Oct-07	20.81	0.82	1.50
Nov-07	45.67	1.81	3.29
Dec-07	28.79	1.14	2.07
Jan-08	26.93	1.07	1.94
Feb-08	40.22	1.59	2.90
Mar-08	39.49	1.56	2.84
Total per Year	**316.25** Estimated. Vol. (m^3) needed	**12.51** total acres/year	**22.77** total Mbf/year

The Amount of Biomass Needed to be Harvested Results:

Utilizing the equation **E = (1/3.6) ηϕ DB** it was possible to find the volume (m^3) of biomass needed per month, to supply the campus's energy demands; giving an overall yearly total of 316.25 m^3 of biomass volume needed to adequately supply the year round energy demands of the campus [As seen in Table 5.4]. From here, given the total volume (m^3) needed per year, it was possible to calculate the total acres needed to be harvested per month and per year to supply the campus's energy demands by utilizing the variables and assumptions above. It was calculated that a volume of 22.77 m^3/acre is generated from non-commercial thinning projects and 13.88 m^3/Mbf is generated from commercial timber projects. This will result in an estimated 12.51 acres/year needing to be harvested from purely non-commercial thinning projects or an equivalent of 22.77 Mbf/year needing to be generated from commercial timber projects [As seen in Table 5.5]**.** It was possible to go further to estimate the amount of posts needed to be harvested commercially for timber projects to produce the necessary 22.77 Mbf/year of biomass. If 22.77 Mbf/year is necessary to supply the campus's energy demands, then it would require the harvesting of 4,592 cords of wood per year which is equivalent to 619,903 posts which would need to be harvested in one year. Obviously, one year of total commercial timber harvesting is out of the question. It is apparent that commercial timber harvesting yields much less usable biomass since the timber is being used for commercial purposes such as for building construction materials. The unusable leftover refuse material after commercial processing would be the biomass which could be utilized by the Environmental Learning Center for energy.

Carbon Offset through the Utilization of Biomass:

Earlier, this study analyzed the amount of carbon given off by both the electricity and propane usage respectively. Woody biomass gives off an estimated 195 lbs of CO_2 per 1 Mbtu (Energy Information Administration, 2008) and so it was then possible to calculate the lbs of CO_2 which will be given off per month of biomass usage for energy consumption [See Table 5.6].

Table 5.6- Energy demands and equivalent lbs of CO_2 released per month

	MWh/Month	Mbtu/Month output needed	Equivalent lbs of CO_2 released per month
Apr-07	49.87	170.17	33,182.38
May-07	41.91	142.98	27,881.29
Jun-07	26.79	91.42	17,827.73
Jul-07	22.48	76.71	14,957.48
Aug-07	27.46	93.69	18,269.31
Sep-07	21.12	72.05	14,049.92
Oct-07	34.52	117.78	22,966.36
Nov-07	75.76	258.48	50,403.83
Dec-07	47.76	162.94	31,773.70
Jan-08	44.67	152.40	29,718.28
Feb-08	66.71	227.60	44,382.60
Mar-08	65.50	223.47	43,577.60
Total per Year	**524.53**	**1,789.69**	**348,990.50**

Carbon Offset Through the Utilization of Biomass Results:

Given that woody biomass gives off an estimated 195 lbs of CO_2 per 1 Mbtu (Energy Information Administration, 2008) it was possible to calculate the lbs of CO_2 which will be given off per month of biomass usage for energy consumption. This gives an estimated value of 348,991 lbs of CO_2 per year that the burned biomass will release. That is almost two times more lbs of CO_2 than what the combined propane and electricity give off in a year. Yet, is has been stated that biomass contains "biogenic" carbon and biogenic carbon is part of the natural carbon balance and it will *not* add to atmospheric concentrations of CO_2 (Yemshanov, 2008) (Energy Information Administration, 2008). With this in mind, essentially biomass is “carbon free” and does not generate or add to the greenhouse gasses within the atmosphere. Electricity and propane are forms of energy generated from fossil fuels which are known to produce carbon which adds greenhouse gasses to the atmosphere. The differences between "biogenic" carbon given off by biomass versus carbon given off by fossil fuels will be discussed greater detail in the "Discussion" section.

Distance and Transportation Costs:

The maximum driving distance that a truck hauling biomass fuel would need to drive is approximately 9.5 miles each way to deliver the biomass from the North Shore to the Environmental Learning Center's biomass power plant (Google Earth, 2008). Most often, a truck hauling biomass fuel would drive approximately 3.0 miles or less to deliver fuel from within the peninsula to the Environmental Learning Center's biomass power plant (Google Earth, 2008). Typically, fuel is hauled ½ ton, to 1 ton at a time (Coyle, 2008). In this analysis it is assumed that to transport biomass, the Ponderosa State Park will be hauling 1 ton of biomass at a time, using a truck which gets an average of 16 mpg. It is estimated that 1 gallon of gasoline will generate 19.564 lbs CO_2 (Energy Star, Energy Unit Converstion Table, 2008) [See Table 5.7].

Table 5.7- Driving trip distances, gasoline usages, and equivalent lbs of CO_2 released per trip

	Round trip distance (mi)	**Gallons of gasoline used**	**lbs of CO_2 given off per trip**
Maximum (West shore route)	19	1.1875	23.23225
East shore route	14	0.875	17.1185
Length of peninsula	6	0.375	7.3365
Width of peninsula	1	0.0625	1.22275

To get an idea of how many lbs of CO_2 can be generated due to transportation, it is necessary to go back to the calculated monthly acres of biomass needing to be *non-commercially* harvested to support the Environmental Learning Center's energy needs and the equivalent tons of biomass which would need to be harvested from those acres every month.

Next, there will be varying round-trip driven distances between 0 miles and 19 miles, but as an estimate, it is assumed that the average round trip distance is 6 miles to haul 1 ton of biomass. Since the truck can only carry 1 ton of biomass at a time, and because this analysis is assuming that the truck will haul 1 ton of biomass every trip; from this, it is possible to calculate the amount of trips needed and the amount of CO_2 given off per round trip. Next it is possible to figure out the monthly carbon generated in transportation of the biomass [See Table 5.8]. This will be a vague estimate, and assumes 100% non-commercial thinning as the method to supply all biomass to the campus, and it also assumes a general truck fuel efficiency and trip distance, yet it still serves to demonstrate the carbon cost of transportation, even if it is from a local source.

Table 5.8- Acres of biomass to be thinned, volume of biomass generated, and equivalent lbs of CO_2 generated per year for biomass transportation

	Acres/Month to be thinned	Tons/Acre of biomass generated	lbs of CO_2 generated per year.
Apr-07	1.19	12.49	91.66
May-07	1.00	10.50	77.02
Jun-07	0.64	6.71	49.25
Jul-07	0.54	5.63	41.32
Aug-07	0.66	6.88	50.47
Sep-07	0.50	5.29	38.81
Oct-07	0.82	8.65	63.44
Nov-07	1.81	18.98	139.23
Dec-07	1.14	11.96	87.77
Jan-08	1.07	11.19	82.09
Feb-08	1.59	16.71	122.60
Mar-08	1.56	16.41	120.38
Total per Year	**12.51**	**131.40**	**964.04**

Transportation Carbon Costs Results:

In the Distance and Transportation Costs analysis above, it was possible to generate some rough estimates of the carbon costs of transporting the necessary biomass from around the Ponderosa State Park to the McCall Field Campus site. Assumptions made were an average

16 mpg truck fuel efficiency, an average round trip distance of 6 miles, and the fact that 1 gallon of gasoline will generate 19.564 lbs CO_2 (Energy Star, Energy Unit Converstion Table, 2008). Assuming this and that all biomass was harvested through non-commercial thinning projects, 964.04 lbs of CO_2 are generated annually in the transportation of the biomass. Assuming that biomass itself does not give off any fossil-based CO_2 and that the campus gives off an estimated 176,434.61 lbs of CO_2 every year through their electricity and propane usages, this results in a net savings of 175,470.57 lbs of CO_2 every year. The Environmental Learning Center would only need to contribute enough energy back into the McCall grid so as to offset the 964.04 lbs of CO_2 due to transportation.

Discussion:

As said earlier in the results section “Carbon Offset Through the Utilization of Biomass”, there is a difference in the CO_2 given off by the biomass and the CO_2 given off by the propane and electricity. Biomass energy is an attractive option from a carbon viewpoint, because the carbon in all wood and wood waste will eventually end up in the atmosphere, so it makes sense to recover the stored solar energy through controlled combustion (Buchanana, 1999)**.** It is true that the burning of biomass speeds up the conversion to carbon dioxide, but this results in a reduction of greenhouse gas emissions if the biomass energy replaces fossil fuel energy (Buchanana, 1999) (Yemshanov, 2008)**.** Biomass contains "biogenic" carbon and under international greenhouse gas accounting methods developed by the Intergovernmental Panel on Climate Change, biogenic carbon is part of the natural carbon balance and it will *not* add to atmospheric concentrations of CO_2 (Energy Information Administration, 2008). One first impression is that biomass fuels and fossil fuels are not different because, when burned, both yield carbon dioxide (Yemshanov, 2008) (Cushman, 2006). However, growing trees and other plants remove carbon dioxide from the atmosphere during photosynthesis and store the carbon in plant structures (Yemshanov, 2008) (Cushman, 2006). This is called “carbon sequestration”. Carbon sequestration by forest biomass can be achieved in two ways (Yemshanov, 2008). The first is the temporary carbon sequestration by forest biomass achieved through forest replanting and regeneration (Buchanana, 1999) (Yemshanov, 2008). The world's forests contain a huge reservoir of carbon (Buchanana, 1999).

> “A sustainable balance can be achieved only if wood growth through replanting and regeneration equals or exceeds the removal of wood. Under these circumstances forest pools will maintain a carbon reservoir at a constant or increasing level. Increasing the size of the carbon reservoir in a forest can only be achieved while the forest is producing an increasing amount of biomass, because the reservoir stops increasing once the forest reaches maturity or steady state management is implemented. A forest managed for sustained production is in a long-term neutral position with regard to carbon emissions because the carbon released following logging of one stand is balanced by carbon absorbed during growth of other stands. An undisturbed natural forest is also in a neutral position with regard to long-term carbon emissions” (Buchanana, 1999).

The second possible sequestration benefit uses forest biomass as a substitute for fossil fuels (Yemshanov, 2008). Carbon is offset by preventing emissions from the fossil fuels which would otherwise have been used. The displaced carbon from fossil fuels and the carbon sequestered in forest biomass have different lifetimes (Yemshanov, 2008). When the biomass is burned, the carbon released back to the atmosphere will be recycled into the next generation of growing plants (Cushman, 2006). The use of fossil fuels occurs once and it is irreversible (Yemshanov, 2008) as fossil fuels are not renewable, nor carbon neutral. When biomass is used for fuel in place of fossil fuels, the carbon in the displaced fossil fuel remains in the ground rather than being discharged into the atmosphere as carbon dioxide (Cushman, 2006).

A second impression is that biomass energy systems, because they recycle carbon, produce no net emissions of carbon dioxide (Energy Information Administration, 2008) (Cushman, 2006). Yet it takes some energy, much of it now provided by fossil fuels, to grow and harvest biomass fuel crops and to haul the fuel to a power plant which have been discussed and accounted for in section “Distance and Transportation Costs”. Although biomass harvesting may result in less carbon stored in standing biomass and forest soils, biomass fuels replace some of the fossil fuel that would otherwise be burned (Yemshanov, 2008) (Cushman, 2006). The carbon in that fossil fuel remains stored in the ground rather than being released to the atmosphere (Cushman, 2006).

In 1895 tree density within the Ponderosa State Park ranged from 8 to 56 trees per acre, with an average of 35 trees per acre (Ponderosa State Park, 2003). Within 25 years, by around 1920, tree density had increased to an average of 121 trees per acre, with a range from 40 trees per acre to 280 trees per acre (Ponderosa State Park, 2003). McCall had been settled, fire control had taken place and tree composition had shifted to under story vegetation of Grand Fir and Douglas Fir, grass and shrubs (Ponderosa State Park, 2003). By 1994, one hundred years after settlement of the McCall area, tree density averaged 141 trees per acre, with a range from 60 trees per acre to 270 trees per acre and dense under-story vegetation of Grand Fir, Douglas Fir, and shrubs has been established (Ponderosa State Park, 2003). With the significantly increased tree density within the Ponderosa State Park, one can say that the Park has a higher carbon sequestration capacity than it previously had in 1895. Between 1895 and 1994 the average density of trees increased over four fold. Current Ponderosa State Park fire management thinning practices are to remove trees less than eight inches in diameter (Coyle, 2008). Thinning practices also include the pruning of lower limbs up to eight feet high to prevent fire ladders (Ponderosa State Park, 2003).

Upon examination of the results, it is apparent that biomass harvested from the Ponderosa State Park is most abundant when it is retrieved from non-commercial thinning since 1 acre of area being thinned will generate approximately 10.5 tons of biomass debris. In a given year, 12.51 acres would need to be non-commercially thinned to supply the proposed Environmental Learning Center with the biomass it would need to satisfy its energy demands. Since there are 1,490 acres which the park manages, there are ample acres of forest from which to supply the biomass needed. Of course, there will be commercial projects within the park which will generate 5.77 tons of biomass per 1 million board-feet (Mbf) of commercial timber (Coyle, 2008). It is apparent that one year worth of biomass needed to supply the proposed Environmental Learning Center cannot be wholly gathered through commercial harvesting, the majority would need to come from non-commercial thinning. It is still unclear as to what biomass percentages can be generated by commercial harvesting and non-commercial thinning yearly compared to one another, but the majority, it is safe to say, would need to come from non-commercial thinning fire management practices.

If only 12.51 acres of forest needs to be thinned for fire mitigation purposes to supply the proposed Environmental Learning Center with the biomass it needs, it would take over one hundred years for all forest acres to be thinned in this manner. As stated previously, some commercial thinning will be carried out within the forest as well, though it is unsure how much. It takes approximately sixteen years for a tree to reach eight inches in diameter measured at a four and a half foot height from the ground (Roth II, 1983). With only a sixteen year turnaround time for new trees needing to be removed, it would appear that more biomass is generated by the Ponderosa State Park than would be needed by the proposed Environmental Learning

Center. This excess could be dealt with by incorporating more commercial harvesting projects as the market, and the Ponderosa State Park, sustainably allow for. Another idea is that the excess biomass generated could possibly be sold to neighboring business or schools that might choose to follow the Environmental Learning Center's lead and switch to biomass power generation.

Thus far in the United States, there are no "Carbon Neutral" Environmental Learning Centers in existence (Westerfield, 2008). The University of Idaho's McCall Carbon Neutral Environmental Learning Center would be the first. IslandWood is a highly acclaimed Environmental Learning Center due to its reclamation of building materials, living machine, and energy interface. IslandWood had shown that children who are exposed to such forward thinking sustainability concepts become environmentally "aware" citizens who have the potential for greater future change (Blanchard, 2007) (Lasala, 2007). It is the University of Idaho's hope that through the McCall Carbon Neutral Environmental Learning Center that the children of Idaho will have access to an original pedagogy of what carbon neutrality means and how it can be achieved through building design and construction techniques, and energy capture and generation methods. It is hoped that by exposing children to such an example of sustainability of the built environment that they will have greater comprehension of humanity's responsibility to the environment and the tools to be better stewards of the biosphere.

Conclusion:

The goals of this feasibility assessment were to first identify the project location and its relationship to the Ponderosa State Park; identify the Ponderosa State Park as the main source of biomass for the proposed Environmental Learning Center; identify the amounts of biomass set forth by the Park's Natural Resource Plan and park manager Dennis Coyle, which can be harvested from the forest; to calculate the current energy usage of the McCall Outdoor Science

School and the equivalent carbon footprint of the campus in its energy needs; to calculate the amount of biomass needed to be harvested on a monthly and yearly basis from the Ponderosa State Park; to calculate the carbon emission equivalent produced or saved through the utilization of biomass; and lastly, to define an average distance from the McCall Outdoor Science School to biomass harvest locations and then calculate the carbon costs for transporting the biomass needed to supply the campus's energy demands.

This feasibility assessment has shown that a collaborative partnership between the McCall Outdoor Science School and the Ponderosa State Park would greatly benefit both parties, and the greater state of Idaho. As it would be Idaho's only Carbon Neutral Environmental Learning Center, the new campus will be uniquely poised to showcase sustainability in a state that is expected to experience a 50% rise in population in the next three decades but which lacks the necessary models for sustainable growth to facilitate such an increase without compromising environmental quality. Thousands of visitors each year will participate in programs that use the Environmental Learning Center's architecture as pedagogy. People will be able to learn what biomass is, how biomass works for energy generation, the sustainability of biomass, and the enormous carbon savings that biomass provides. The Environmental Learning Center will be able to achieve one of the goals for carbon neutrality by generating its own energy onsite via the use of sustainable underutilized materials such as biomass. Likewise, the Ponderosa State Park will have a market in which to sell their residual biomass to and can fund future projects which will aid in the fire management practices of the forest.

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Chapter 6: Feasibility Assessment of Straw Bale Construction

Straw Bale History:

In the United States, the earliest record of straw bales homes were built in the latter 1800's and early 1900's by settlers in the Sandhills of Nebraska (Sustainable Sources, 2006) (DayCreek Journal, 2008). This geographic area was void of trees, roads, or railways, and settlers were forced to build out of the materials that they could find locally (DayCreek Journal, 2008). Also, most settlers lacked the money to build a more conventional style of house and the straw bale houses were initially built only to be temporary (DayCreek Journal, 2008). As other building materials such as wood became more prevalent, the straw bale technique waned. Although straw bale houses were frowned upon as an inferior building method, today they have plenty of merit (DayCreek Journal, 2008).

Straw bale construction uses baled straw, not hay. Straw is the leftover stems of harvested cereal grains which are sometimes used for bedding material for animals (DayCreek Journal, 2008). Straw is the dry plant material, or stalk, left in the field after a plant has matured, been harvested for seed, and is no longer alive (Sustainable Sources, 2006). Baled straw that can be used for straw bale construction can come from various grains such as wheat, oats, barley, rye, and rice. Straw bales are traditionally a waste product which farmers do not till under the soil, but do sell as animal bedding or landscape supply due to their durable nature (Sustainable Sources, 2006) (DayCreek Journal, 2008). In many areas of the country, if the residual straw is not baled it is burned, causing severe air quality problems. Two hundred million tons of straw are burned annually in the US. The stability and lack of weathering in straw is not desirable in the realm of agriculture but quite desirable in construction (Sustainable Sources, 2006).

Straw Bale Building Types:

There are two major categories of straw bale construction: load-bearing and non-load bearing. A post and beam framework that supports the basic structure of the building, with the bales of straw used as infill, is the most common non-load bearing approach (Hart, 2001) (Sustainable Sources, 2006) (DayCreek Journal, 2008). The non-load bearing construction method is also the only method that many building authorities will allow. Non-load bearing straw bale construction uses either timber, steel, or concrete post and beam frame construction can use bales as infill. The frame adds to the expense in materials and in labor for constructing it and then it involves working around the frame with the bales (Sustainable Sources, 2006).

While there are many load-bearing straw bale buildings that are still standing, care must be taken to consider the possible settling of the straw bales as the weight of the roof compresses them one to two inches from the original wall height (Hart, 2001) (Chiras, 2000, p. 76)**.** Due to the compression of the bales under the weight of the roof, structural straw bale construction requires that the bales sit for a short period of time to complete any settling before stucco is added, or that the walls be mechanically pre-compressed. If the bales are firm, there will be very little settling, typically less than 1 inch (Sustainable Sources, 2006). A wire tie-down system which is connected from the foundation to the top plate may also be used to firm up the wall and compress it to compensate for any settling concerns (Sustainable Sources, 2006).

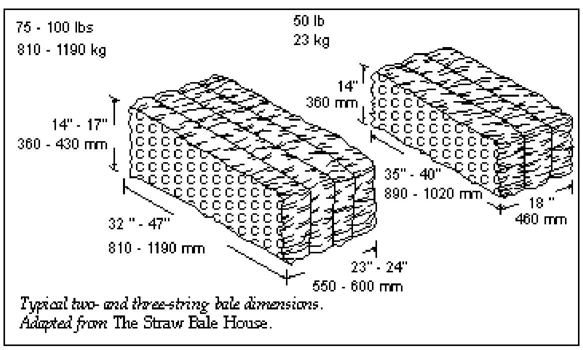
Straw Bale Specifications:

The bales used for house construction come in various sizes typically held together with two or three strings (DayCreek Journal, 2008) (Sustainable Sources, 2006). The larger three string bale is typically 23" x 16" x 42" and weighs about 80lbs. The smaller two string bale is typically 18" x 14" x 36" and weighs about 55lbs (DayCreek Journal, 2008) (Sustainable Sources,

2006) (StrawBale Innovations, LLC, 2007). The actual measurements of all these bales may vary depending on the baling machines employed in the fields. You will need to know the exact size of the bales you will use when you are designing the structure. It is good practice to design to the size of the bale (StrawBale Innovations, LLC, 2007). Approximately eight to ten acres can sufficiently supply the amount of straw needed to build a small house. The best time to obtain straw is at harvest time, roughly May through June (Sustainable Sources, 2006). Moisture content is another important factor in deciding which bales to purchase. Moisture content of up to 20% is considered safe although the less moisture the better. It is preferable to find bales that have a moisture content of 8% to 10%. Moisture content will vary with the ambient moisture, so areas with high humidity may have bales with more moisture. There is a way to calculate moisture content in bales mathematically; however, hand held moisture meters are the easiest way to check moisture content. It is important to be sure to keep the moisture levels below 20% at all times (StrawBale Innovations, LLC, 2007). Density is also important to consider. A tightly strung bale will create a solid wall and strong backing for the plaster. A general rule of thumb is that when the bale is lifted by one string, there should be very little shape deformation. Also, bales should not greatly deform when dropped from a pickup truck bed (StrawBale Innovations, LLC, 2007).

In straw bale construction, the bales can either be lain flat or on edge to form the walls. The bales are best used flat for structural purposes, but it makes the wall a bit wider. Also when bales are laid flat, plaster will "key" into the ends of the straw, whereas bales on edge will have the long length of the straw on the wall surface, providing a weaker bond between the plaster and the bale (Sustainable Sources, 2006). During construction, the straw bales are typically stacked like bricks and are reinforced vertically (DayCreek Journal, 2008). The bales are anchored to each other when stacked by stakes of wood, rebar (#3 or #4), or bamboo that penetrate at least two bales in depth. Such anchoring is generally accepted to be primarily necessary to keep walls from toppling during construction.

The straw bales are typically sealed by finishing the outside wall with stucco cement and plaster on the interior (DayCreek Journal, 2008). Poultry netting can be mounted on both sides of the walls to help the plastering process. Well applied plaster will usually provide sufficient stability once complete, though by that time, whatever pinning method was used will be embedded in the walls (Sustainable Sources, 2006). Stucco lath is used around windows, doors, and corners for added strength. The wire netting and lathe are typically held against the bales by wire ties through the bales or pins into the bales (Sustainable Sources, 2006) (Chiras, 2000). Utilities can be laid in the walls as they are built, laid against the bales after the walls are built, or run in moldings, interior walls, under floors, or in the attic (Sustainable Sources, 2006).



6.1 Typical straw bale dimensions (DayCreek Journal, 2008).

6.2 Straw bale construction. Image from Ecobob.co.nz (Cumming, 2007).

Straw Bale Construction and Water:

The greatest enemy of straw bale construction is water. People often question whether moisture is a problem and seem to equate moisture with water. There is a difference yet both can be detrimental, one more so immediately detrimental than the other. In the right climate, moisture can enter a wall and exit a wall in a short enough period of time so not to cause damage (StrawBale Innovations, LLC, 2007) (Skillful Means, 2008). For example, it is typical for a home to drive moisture through the walls to the exterior during the cold winter months when interior heating both creates and moves moisture towards the cold exterior. As long as this moisture is allowed to escape to the outside, there will not be a problem. In straw bale construction, the use of vapor barriers can be detrimental. Vapor barriers hold the moisture in the walls, and the damage can be extensive (StrawBale Innovations, LLC, 2007). The idea of eliminating vapor barriers, like Tyvek® and Typar®, may seem strange to builders coming from the conventional building world. Yet vapor barriers are not used in straw bale construction other than to protect the bottom courses from rain splash. Although, in theory, a dew point can occur within the bale walls during winter months, practice indicates that walls without exterior moisture vapor barriers perform well, even in cold climates (Skillful Means, 2008).

Straw bale buildings, by their very nature are organic and are liable to suffer degeneration due to certain combinations of moisture and temperature. Fungus, also known as dry rot, can occur in straw at humidity levels of above 20% (Goodhew, 2004) (Skillful Means, 2008). Ideally, moisture levels of straw bales in use and in storage should be below 14% as this is below the level that is believed to allow biological activity to begin (Goodhew, 2004) (Sustainable Sources, 2006).The most common method used to measure the moisture content of straw-bale wall is the wood-disc sensor. This is mainly because they are cheap, easy to read, and are viewed as being reasonably accurate (Goodhew, 2004). In order for significant damage to occur, these humidity levels must be maintained over a period of time. Once the bales dry out, the fungus will die. Consequently intermittent moisture is not a threat to bales. However, sustained high levels of moisture must be avoided. Experience and test results suggest that the best way to avoid sustained high moisture concentrations lies in making certain that the bales are able to transpire any accumulated moisture back into the environment (Chiras, 2000) (Skillful Means, 2008).

In straw bale construction, openings present the biggest risk to water infiltration. Proper flashing is essential. Likewise in straw bale construction, water pipes are not placed in the bale walls and the bales never sit directly on the ground. Plumbing is either relegated to interior walls or is protected by continuous sleeves or faux wall construction. For additional protection from water damage, minimum, 3 ½"-6" toed-up stem wall should be incorporated for the bales to sit on, this keeps water that may pool on the ground from coming in contact with the straw bale walls (Chiras, 2000, p. 70) (StrawBale Innovations, LLC, 2007). The toe-up provides a break in the sub-straight so that no water can possibly wick into the bales. Therefore, the walls stay dry and the damage is only reflected in the flooring (Chiras, 2000) (StrawBale Innovations, LLC, 2007).

Although opinions vary widely, the consensus among natural builders is that a breathable wall is necessary. It is essential to use a coating that will allow moisture to pass through a straw bale wall with ease (Chiras, 2000, p. 80). Unlike cement stucco, earthen plasters adhere very nicely to straw bale without any assistance from stucco netting. Earthen plasters not only reduce labor costs, they allow air and moisture to move through the walls. The plasters prevent moisture from building up inside the straw bale wall, which reduces the chance of mildew forming in the wall and the straw from rotting out (Chiras, 2000, p. 80). Although most straw bale homes are stuccoed or plastered, some builders also apply siding on the bale walls. This practice is most common in wet climates; in places where driving rains soak exterior walls and there are not enough warm, sunny days in between storms to permit the walls to dry out. In such instances, the siding prevents driving rains from penetrating the walls and saturating the straw (Chiras, 2000, pp. 83-84).

Fire and Pests:

Straw-bale construction is exceptionally resistant to fire due to the fact that the straw bales are dense and difficult to burn. If ignited, straw bales burn like heavy timbers. Baled straw chars and smolders and does not easily support a flame. This is because the straw in the bales is densely packed, inhibiting oxygen flow to fuel combustion. However, once started, fires are difficult to extinguish, as the embers tend to slowly tunnel through the bales (Skillful Means, 2008). When jacketed by stucco and plaster, bales are highly resistant to fire. It is therefore important that bales which could be exposed to extreme heat or flame, whether in walls or roofs, be encased in plaster sheet rock, and/or stucco netting (Chiras, 2000) (Skillful Means, 2008).

Compared with wood, there are few termites who like straw. The straw in straw bale structures have not shown evidence of termite infestations (Sustainable Sources, 2006).The straw bales provide less space for pests than conventional wood framing, it would be very difficult for pests to travel through the bales. Should rodents enter a wall at a break in the plaster coating, they would be likely to make a cozy place to stay. However, straw contains very little nutritional substance and will not support a pest population. Conventional precautions against pests should be more than adequate for straw-bale (Skillful Means, 2008).

Embodied Energy and Insulation Values:

In 1998, Pierquet et. al. conducted a study of the insulation value and embodied energy of twelve different wall types, including cordwood and straw bale. Pierquet conducted an analysis of embodied energy versus thermal performance which can be very helpful in determining the environmental friendliness of various building systems. The study finds that of the two historic vernacular building systems modeled in the study, straw bale construction appeared to be much superior to cordwood construction in terms of long-term energy performance, yet both of these wall construction methods required less embodied energy compared to all other wall construction methods.

Straw bale walls have been tested for heat transmission, and have been rated as high as R-55 (Skillful Means, 2008). A conservative number, used by the California Energy Commission, is R-30. Straw bale construction typically exhibits R-values ranging from R-30 and up to R-45 (Sustainable Sources, 2006). Pierquet's study looks at three different straw bale walls and the R-values range from R-44.8, to R-34.1 to R-23.2. The study estimated that the embodied energy of a straw bale wall is 0.70 $Mj/ft.^2$ of wall area. Likewise, the study estimated that the embodied energy of one 2-string bale of straw to be 2,316 BTU's, when they study accounted for transportation, the estimated energy for generating one bale of straw was postulated to be approximately 3,200 BTU's. According to Daniel Chiras, the embodied energy required to produce 1 ton of straw is approximately 112,500 BTU's (Chiras, 2000, p. 79). Chiras's estimate that one ton of straw is approximately 112,500 BTU's, is close to Pierquet's generation and transportation estimate. Chiras's estimate suggests that each 55 pound bale requires roughly 3,094 BTU's of energy to produce, he did not specify if transportation was included into his calculation.

To put these values into perspective, if the embodied energy required to produce 1 ton of straw is approximately 112,500 BTU's, in contrast, in order to produce 1 ton of concrete, it requires 5,800,000 BTU's of embodied energy (Chiras, 2000, p. 79). Straw bale not only requires little energy to produce, it also is has one of the highest insulation values. If straw bale is conservatively estimated to have an R-value of R-30, cordwood was found to have an R-value of R-20.5 by Pierqute's study (Pierquet, 1998). Pierquet's study also finds that a conventional 2 x 6 wall with fiberglass insulation to have an R-value of R-22.2 (Pierquet, 1998). Both cordwood and

2 x 6 construction with fiberglass insulation do not measure up to the insulating value that straw bale provides.

Advantages of Straw Bale Buildings:

- Straw bale homes are produced from an abundant and highly renewable resource, a by-product of grain production that is often burned after the grain is harvested, creating enormous amounts of air pollution (Chiras, 2000, p. 93) (StrawBale Innovations, LLC, 2007).
- Straw is readily available and easy to acquire in most locations and has little if any impact on the well being of the planet. Using a natural insulator as a wall is a great way to reduce consumption of non-earth friendly building materials (DayCreek Journal, 2008) (StrawBale Innovations, LLC, 2007) (Chiras, 2000, p. 93).
- Load bearing straw bale construction requires much less lumber than traditional wood frame construction and could reduce deforestation (Chiras, 2000, p. 93). If built as a load bearing assembly, the wood in the walls can be completely eliminated, except for around the windows. The harvesting of forests is a global concern and any reduction in the use of wood material is a good thing for the long term health of the planet. Even non-load bearing, infill straw bale homes can reduce the use of wood by using engineered lumber for the posts and beams. The engineered material uses smaller, faster growing trees in place of larger, slower growing species (StrawBale Innovations, LLC, 2007).
- Straw has low embodied energy. The amount of energy that it takes to make straw is substantially less than other building materials used to build a stick frame house. (DayCreek Journal, 2008) (Chiras, 2000, p. 93).

- Properly built straw bale walls are safe, strong, durable, and long lasting (Chiras, 2000).
- Stuccoed and plastered straw bale walls are fireproof, rodent and insect proof, and if kept dry, resistant to decay (Chiras, 2000, p. 94).
- Straw bale homes are suitable for a wide range of climates (Chiras, 2000, p. 94).
- Straw bale walls provide an extraordinary measure of insulation, helping to ensure a thermally stable environment. By keeping homes cool in the summer and warm in the winter, they conserve energy (Chiras, 2000, p. 94). Straw bale walls provide excellent R values of about R-28 (DayCreek Journal, 2008). Some estimate the R-value as generally ranging from R-30-R-45 (Pierquet, 1998) (Sustainable Sources, 2006).Plastering the interior wall of a straw bale house adds some thermal mass as well. Both superior insulation and thermal mass give good start towards a very energy efficient house (DayCreek Journal, 2008).
- The use of straw as insulation means that the standard insulation materials are removed from the home. Standard fiberglass insulation has formaldehyde in it, a known carcinogen. Bale walls also eliminate the use of plywood in the walls. Plywood contains unhealthy glues that can off-gas into the house over time (StrawBale Innovations, LLC, 2007).
- Thermal properties make this construction technology suitable for passive solar heating and cooling systems (Chiras, 2000, p. 94).
- Properly built straw bale homes require much less energy (about 30 times less) than standard wood-frame walls insulated with fiberglass batting (Chiras, 2000, p. 94).Straw bale homes require less energy to heat and cool and thus decrease our dependence of fossil fuels, thereby reducing air and water pollution, oil spills, and land disturbance (Chiras, 2000, p. 94). A well built straw bale home can save up to 75% on heating and

cooling costs. In fact, in most climates, people do not even install air conditioning units into our homes as the natural cooling cycles of the planet are enough to keep the house cool all summer long (StrawBale Innovations, LLC, 2007). But in general, the lowered heating and cooling costs reduce the size of backup heating and cooling systems, thus saving money (Chiras, 2000, p. 94).

- The insulation value of straw bale walls provide excellent sound insulation and are superior wall systems for home owners looking to block out the sounds of traffic or airplanes in urban environments (StrawBale Innovations, LLC, 2007) (Chiras, 2000, p. 94).
- Erecting straw bale walls can go amazingly quickly, and does not take a lot of skill (Hart, 2001). Just like cordwood, almost anyone can build a straw bale house. Basic carpentry skills and a little muscle is all that is needed (DayCreek Journal, 2008). Straw bale walls can be built with relatively simple tools and relatively untrained workers. Individuals can learn what they need to know to stack walls in a two-day workshop (Chiras, 2000, p. 94).
- Straw bale construction is productive to community participation and owner-builder projects (Chiras, 2000, p. 94).
- Straw bale construction is flexible, allowing one to build in a variety of different styles. Straw bales can be used in conjunction with other natural building methods, such as rammed earth, or even conventional building techniques (Chiras, 2000, p. 94).
- As straw bale construction becomes more widely known, it becomes easier for the owner-builder to obtain building department approval, financing, and insurance (Chiras, 2000, p. 94).
- When covered with plaster, straw bale walls resemble thick adobe walls (Chiras, 2000, p. 94).

- Depending upon what fixtures go into the building, costs run anywhere from $5 to well over $100 a square foot. In general though, one could probably build a straw bale home for about the same cost as a cordwood home. Typically the only part of the house that is different from either building method is the walls. Costs vary depending upon whose labor is use (yours vs. paid labor), windows, doors, fixtures, etc. The more that can be done by yourself the less it will cost out of pocket (DayCreek Journal, 2008).
- Straw bale homes have roughly three times the fire resistance of conventional homes. Dense bales mean limited oxygen which in turn means no flames (StrawBale Innovations, LLC, 2007). According to Mother Earth News, Jan. 1996, once the walls are sealed with stucco, tests show that 18" straw bale walls survived fire penetration for more than two hours. Unfinished walls only survived for 34 minutes (DayCreek Journal, 2008).

Disadvantages of Straw Bale Buildings:

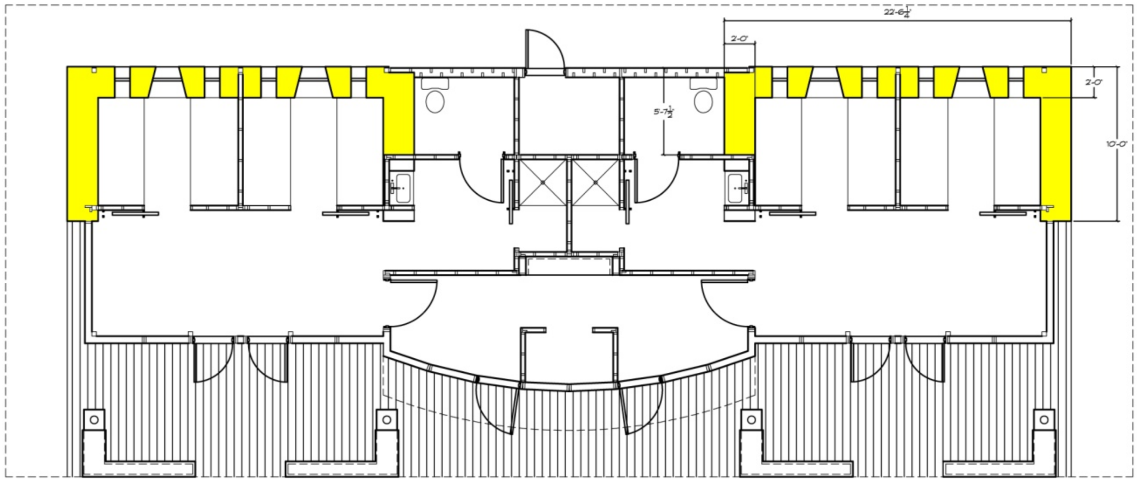
- Despite its growing popularity, straw bale construction is still considered unconventional. Depending upon where you live and the building code standards, you might have a tough time getting approval, obtaining financing, and insurance (Chiras, 2000). There are quite a few good documents that can help make this a less painful procedure. "Straw Bale Construction and the Building Codes" by David Eisenberg is a good reference for those who need some help with a building permit (DayCreek Journal, 2008).
- Straw bale walls may require a thicker foundation than wood-frame homes which adds to the project cost (Chiras, 2000, p. 94).

- Although straw is a waste product that is often burned in fields or plowed under, these practices help replenish agricultural soils by adding vital organic and inorganic nutrients. Diverting straw to build houses could damage soils (Chiras, 2000, p. 94).
- Walls of straw bale must be protected from moisture to avoid mildew and rotting, but so must walls of conventional wood frame homes (Chiras, 2000, p. 94). Studies have shown that if the walls are not allowed to breath properly, moisture buildup within the wall will lead to the straw rotting. Builders should exert caution building in areas that have high humidity (DayCreek Journal, 2008).
- Bale walls are relatively easy to erect, but they represent only a fraction of the total construction project. Don't be lulled into thinking it is easy to build straw bale home. Electricity and plumbing, interior framing, tile, and other features of modern homes will increase substantially the complexity of the project (Chiras, 2000, p. 94).
- Straw bale walls cannot be built underground or earth bermed, although there are exceptions (Chiras, 2000, p. 94).
- Straw bale building is in a state of rapid evolution. As information changes, current building methods may become obsolete or prove inadequate. Therefore, there is some risk involved in building straw bale homes (Chiras, 2000, p. 94).
- Opinions on different aspects of straw bale construction vary considerably, making it hard for the neophyte to know which path to follow (Chiras, 2000, p. 94).
- Only before the plaster and stucco are applied can fire be a potential problem (DayCreek Journal, 2008).
- For post and beam, non-load bearing straw bale construction, the creation of the building is similar to any other wood framed house. In fact post and beam straw bale houses typically only save about 15% of the wood used in a conventionally framed

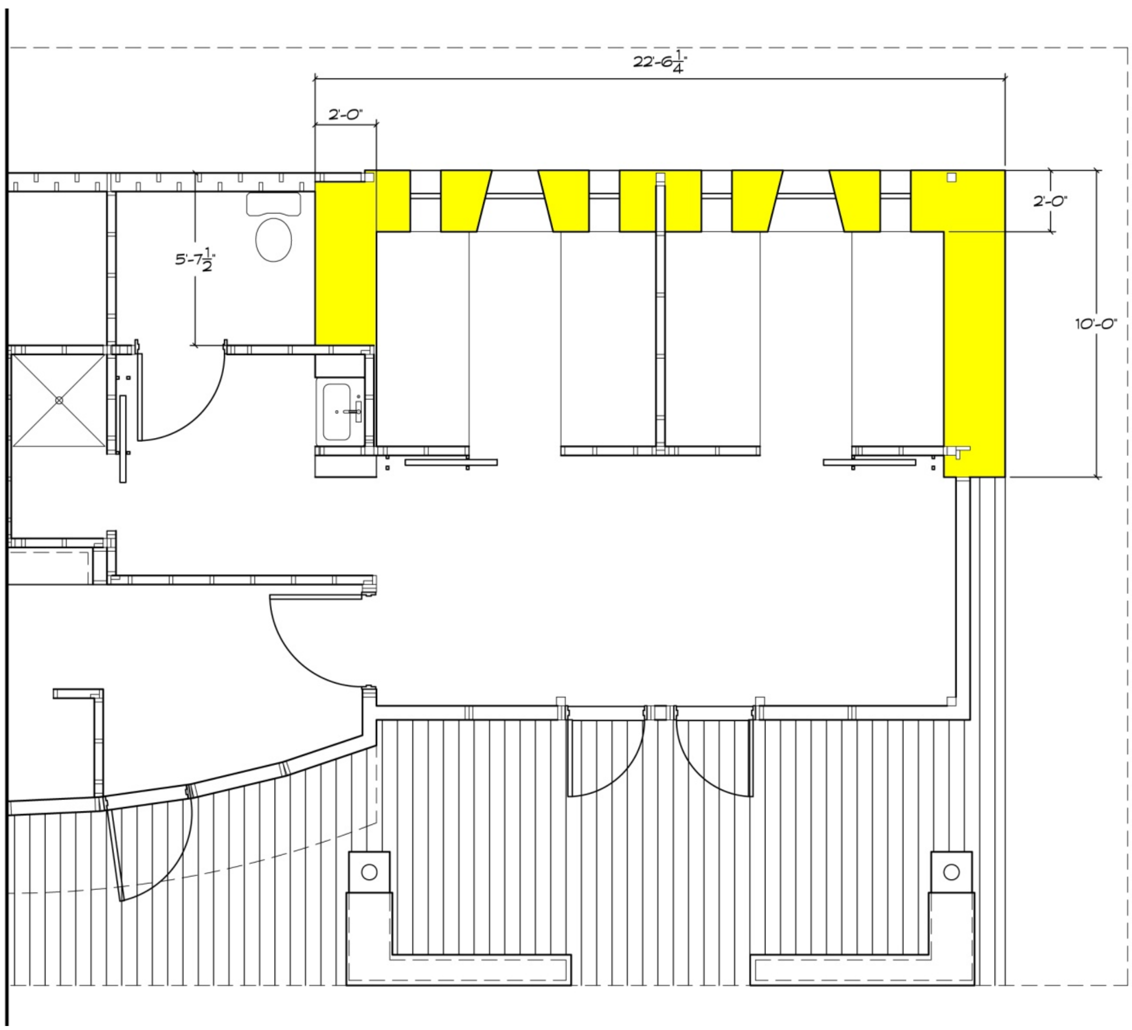
house (Hart, 2001). The cost of finishing a straw bale house can often exceed that of standard construction, because of the specialized work that goes into plastering both sides of the walls. The result is often worth it though, because of the superior insulation and wall depth that is achieved (Hart, 2001).

Calculating the Number of Straw Bales:

Once having designed the straw bale house or structure, it is necessary to figure out how many bales will be needed to build it. One way to estimate the amount of bales the project calls for is to calculate the number based on square footage of the wall surface area. In other words, first calculate the total lineal feet of straw bale wall and then multiply that by the height of the walls. This yields the square footage of wall surface (StrawBale Innovations, LLC, 2007). Next add the areas of all the doors and windows in the building structure and subtract this number from the overall wall area. Once all of the openings have been subtracted, divide the total square footage by the square footage of a single bale. This will give the exact number of bales that will be needed to build the structure. It is not recommend that anyone try to build a house with the exact number of bales, so it is best to add about 10% to the total number calculated (StrawBale Innovations, LLC, 2007). Straw generally costs about $3.50 to $4.00 a bale, buying a few extras will not hurt nearly as much as running out and delaying the job while you try and locate bales of the same size to finish the project (StrawBale Innovations, LLC, 2007). To calculate the amount of bales needed, the following figures 6.3 and 6.4 will be referenced.



6.3 Guest bunkhouse floor plan to be built during the Summer of 2009. Straw bale infill is highlighted. Floor plan was provided by professor Frank Jacobus.(Not to scale)



6.4 A partial guest bunkhouse floor plan illustrating the straw bale wall dimensions. Straw bale infill is highlighted. Floor plan was provided by professor Frank Jacobus.(Not to scale)

Following the procedure to estimate the amount of straw bales needed, the first step is to calculate lineal feet of straw bale wall and then multiply that by the height of the walls. Assuming that the height of the walls is 8ft, the total area of the walls for each half of the building is equal to 273ft^2. Each lodging bay has approximately 10ft^2 of windows, resulting in 20ft^2 of window surface area per half of the building. Subtracting the overall wall area from the window area, the total wall area that will consist of straw bales is 253ft^2. The next step is to calculate the square footage of the bales. For this project, Dave Shuey of Caldwell Idaho will be providing the straw bales. The bales have a moisture content of less than 10%. They are 15”x23”x46” in size and are 3-string bales meaning that they weight approximately 80lbs each. Since the walls will be 24” wide, the bale area that will make up the walls is 15”x46” which is 4.79ft^2 in area. Dividing the total wall area which will consist of straw bales by the bale area that will make up the walls, the amount of bales that will be needed per half of the building is roughly 53 bales. Adding an extra 10% of bales to the total will ensure that there will be enough bales for the project. This gives the total of 58 bales needed per side of the building, thus resulting in a total need of 116 bales for the entire guest bunkhouse. To reach a wall height of 8ft, the straw bales will need to be stacked over six courses high. As a side note, the supplier of straw bale has stated that each straw bale will cost $3.50. The total cost just for the straw bales for this one building will be $406.00. This does not include the costs of other materials, labor, and transportation.

The supplier of straw bale is located in Caldwell Idaho which is approximately 140 miles away. In order to build one building, the project requires 116 bales of straw weighing roughly 80lbs individually, which weighs approximately 9,280 pounds total. Assuming that a truck can carry only one ton (2,000 pounds) per trip, then five trips would need to be made to deliver all of the straw to the field campus. Assuming that the truck averages a fuel efficiency of 16 miles per gallon, the carbon costs of transporting the straw bales is 1,712 pounds of CO_2. If one gallon of gasoline has 125,000 BTU's, and the 280 mile round-trip will use 17.5 gallons of gas, then the total energy to transport the bales is 10,937,500 BTU's. Using the figure of 2,316 BTU's needed to produce one bale of straw that Pierquet denotes, each bale of straw to be used for this project will require 65,906 BTU's of energy to create and transport. This means that to produce and transport the straw, each bale will generate 10.32 pounds of CO_2. Obviously, straw bale construction in McCall is not appearing to be very carbon neutral, though it is still more carbon friendly than using conventional wood frame construction which requires milled and transported lumber, insulation, drywall, and plaster. The reason why the nearest supplier of straw bale is located so far away is due to the McCall region's extremely short growing season and high water table. These two conditions make the local area incapable of growing grains.

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Chapter 7: Feasibility Assessment of Cordwood Construction

Cordwood History:

In America, cordwood structures started appearing with the first settlers who came to Wisconsin. Old World Wisconsin is a village comprised of early settler houses which were built throughout the state by immigrants. In the Old World Wisconsin village, there is a cedar cordwood house that was built by Polish immigrants sometime in the 1880's (Daycreek Journal, 2008). Some cordwood structures estimated to be 1,000 years old are still standing in areas of Siberia and in the northern areas of Greece but the actual original origin of cordwood still remains obscure (Daycreek Journal, 2008). Cordwood masonry is a form of construction that consists of lying whole or split wood, in a bed of mortar. When looking at a cordwood wall, the log ends are the only part of the wood that is visible (Hart, Cordwood, 2001) (Daycreek Journal, 2008). The thickness of the wall is determined by the length of the cordwood used. Typically, walls are anywhere from 6" to 24" thick depending upon the builder's need for thermal insulation (Daycreek Journal, 2008).

Cordwood Specifications:

Cordwood construction is an economical use for log ends or fallen trees in heavily wooded areas. Cordwood construction utilizes short, round pieces of wood, similar to what would normally be considered firewood. For this reason this building method is very resource efficient since it makes use of wood that might not otherwise have much value (Hart, Cordwood, 2001). Common sources for cordwood include sawmills, split firewood, split rail fence posts, and logging slash such as that produced by the Ponderosa State Park. This construction method produces a look that is both rustic and beautiful. It is possible to include other materials into the matrix, such as bottle ends that would allow light to enter the wall (Hart, Cordwood, 2001).

There are two main types of cordwood construction, “throughwall” and “mortar-insulation-mortar” (M-I-M). In throughwall cordwood construction, the mortar mix used contains an insulative material, usually sawdust, chopped newsprint, or paper sludge, in sometimes very high percentages such as 80% paper sludge to 20% mortar (Snell, 2005). Unlike brick or throughwall masonry, in M-I-M construction, neither the mortar nor the cordwood continues throughout the entire wall width. Cordwood walls can be either load bearing using built-up corners, or a curved wall design, or cordwood walls can laid within a post and beam framework which provides structural reinforcement and is suitable for earthquake prone areas. As a load bearing wall, the compressive strength of the wood and mortar allows for roofing to be tied directly into the wall (Snell, 2005).

Once a proper foundation has been poured which rises 12” to 24” above ground level with a splash guard, construction of the walls can begin (DayCreek Journal, 2008). Like straw bale walls, many building authorities require a post and beam or similar supporting structure and then using cordwood as an infill, even though cordwood construction creates a very strong wall that could support a considerable load (Hart, Cordwood, 2001). For a post and beam structure, the wooden frame must first be constructed. To minimize the demand for lumber and to reduce the destruction of old-growth forests, it is important to consider using recycled or salvaged timbers. One of the advantages of the post and beam system is that after the frame is erected, the roof can be built, creating a sheltered working space in which to complete the cordwood mortaring (Daycreek Journal, 2008) (Chiras, 2000). In rainy climates, roof protection can be invaluable (Chiras, 2000, p. 173).

Since the mortar is an integral part of cordwood construction, it is important to get the mortar mix right. Rob Roy, an experienced cordwood builder, recommends using a mortar mix of 9 parts sand, 3 parts sawdust, 3 parts builder's lime, and 2 parts Portland cement (Roy, Cordwood Masonry Houses, 1980). The sawdust used in the mortar should be from softwood and should be able to pass through a ½ inch screen. Saw mills and chainsaw dust are great sources for obtaining sawdust. Sawdust, presoaked in water before use, will act like a sponge from which the mortar can draw moisture. The mortar will dry slowly and will reducing cracking. Builder's lime makes the wall more flexible, breathable, and self healing because it takes longer to completely set than cement. Portland cement chemically binds the mortar and should be either type I or II (Roy, The Charm of Cordwood Construction, 2003). On the other hand, Richard Flatau, in his book *Cordwood Construction: A Log End View (2007)* suggests using a mortar mix of 3 parts sand, 2 parts soaked sawdust, 1 part Portland cement and 1 part hydrated lime. This mix is to be used for a non-load bearing cordwood post and beam framework. This mortar mix has the advantage of curing slower and displaying less cracking than mortars that use less sawdust. Flatau also recommends shading the masonry work from the full sun to help prevent it from drying too quickly and cracking (Daycreek Journal, 2008).

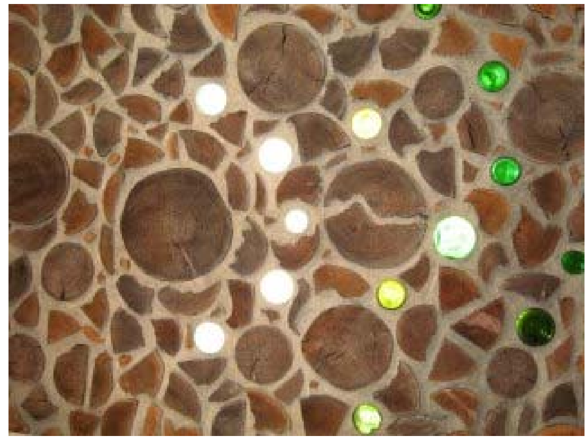
One drawback to cordwood construction is that before construction can begin, significant time must be taken to prepare the wood. The cordwood is gathered and must be dried well before the foundation work even starts. This gathering and drying phase of the project starts a few months to a full year before construction begins. Almost any wood can be used, as long as it is sound. Most builders work with wood newly cut from the forest. They trim the branches off and cut the logs into manageable sections, and then strip the bark from the logs. This facilitates drying and also roots out insects hiding beneath the bark, where they feed on nutrient rich tissues of the trunk (Chiras, 2000, p. 174).

Removing the bark from logs is tedious but one can reduce the amount of work by cutting trees in the spring. The sap is still running in spring time, ascending from the roots where it was stored over the winter to the trunk and branches in order to nourish new growth. The sap provides a lubricating layer of cambium between the bark and wood, making separation an easier task than if left until the fall when the two layers are well-bonded together (Daycreek Journal, 2008) (Chiras, 2000, p. 174). One cordwood builder found that soaking the logs in a stock tank for a week loosens the bark and makes the job a lot easier (Chiras, 2000, p. 174).

Once debarked, the logs should sit to dry in order to limit splitting and checking. It is important to cut the logs, once debarked to the chosen wall depth. For cutting the wood down to the desired length, a metal handsaw such as a buzz saw, will make quick work of cutting cordwood into chosen lengths and is preferable to a chainsaw because the finer cut helps to thwart moisture and pest penetration (Daycreek Journal, 2008). Drying times vary considerably, depending on the climate, the season, and the weather. In summer, drying may require a couple of months. If trees are cut in the fall, however, expect drying to take six to seven months. Never lay the logs on the ground to dry (Chiras, 2000, p. 174). Richard Flatau, *Cordwood Construction: A Log End View* (2007) suggests splitting the wood for better drying and seasoning (Daycreek Journal, 2008). Daniel Chiras discusses the advantages of split wood when he says,

> “Cordwood homes are built out of round or split logs. Although round logs stack up very nicely, most people prefer split wood. It dries faster and allows for more uniform mortar joints. Uniform mortar joints result in a stronger wall. Splitting logs also reduce or eliminates large cracks that develop in large ‘rounds.’ Although wood splitting adds many hours of hard labor to the project, it does reduce the time spent stuffing and caulking cracks” (Chiras, 2000, p. 176).

7.1 A cordwood home in New York called the Pompanuck Farm, www.pompanuck.org (O'Brien, C. and Lee, C., 2007).



7.2 Cordwood wall with bottles which allow light to pass through the wall (O'Brien, C. and Lee, C., 2007)

Cordwood Issues to Consider:

One of the largest problems with cordwood construction is the expansion and contraction of logs which causes wood to crack. Cracks along the length of the log, known as checks, provide an avenue for air movement. If the cracks are not sealed, the cordwood building will be drafty. More problems arise with radial shrinkage, which occurs when the radius of a log decreases as it loses moisture. Radial shrinkage causes the log ends, to pull away from the mortar, creating cracks around the perimeter of each log. Proper drying of the wood before construction permits radial shrinkage to happen before the wall construction commences and thus reduces the size of the cracks around each log end (Chiras, 2000, p. 175). Less dense, airy woods are superior to use in cordwood construction because they shrink and expand in lower proportions than dense hardwoods like elm, maple, oak, and beech (Chiras, 2000) (Daycreek Journal, 2008). Most wood can be used in a wall if it is dried properly and is adjusted to the external climate's relative humidity. Furthermore, logs of identical species and source are preferred because they limit the expansion and contraction variables (Daycreek Journal, 2008).

One of the biggest concerns people have about cordwood homes is that the logs will eventually rot, causing the walls to collapse. Like straw bale construction, rotting, caused by bacteria and other microorganisms, occurs very rapidly when wood is kept damp for long periods of time. Cordwood homebuilders employ several measures to avoid this problem. One of them is to select decay-resistant tree species (Chiras, 2000). While over thirty different types of wood can be used, the most desirable rot resistant woods are Pacific yew, bald cypress, cedars, and juniper. Acceptable woods also include Douglas fir, western larch, Eastern White Pine, Spruce Pine, Poplar, Tamarack, Western red cedar and Monterey pine (Daycreek Journal, 2008). Builders also avoid trees that show any initial signs of decay and protect logs from rain and snow when they are drying (Chiras, 2000, p. 179).

A cordwood house should have deep overhanging eaves of at least 12” to 16” in order to keep the log ends dry from snow and rain and to prevent fungal growth. Good overhangs will protect walls, an adequate foundation is essential also to keep pooled water away from the bottom course of logs (Chiras, 2000). If the ends are maintained and are kept dry, they will age without problem. Typically the logs are not coated with a moisture barrier, but are allowed to breathe naturally (Hart, Cordwood, 2001). Yet some owners have coated the log ends with treatments such as linseed oil, which is a nontoxic sealant, or they set the outside log ends flush with the mortar for further weatherproofing (Chiras, 2000). If log-ends have been treated with sealants to retard water penetration, the logs should be retreated every couple of years. Over time, some checking is normal, and can be remedied with periodic mortar or caulking maintenance (Chiras, 2000).

Embodied Energy and Insulation Values:

Different mortar mixtures and insulation fill material both have an impact on the wall's overall insulation R-value (Snell, 2005). Cordwood construction creates a wall that has both properties of insulation and thermal mass (Chiras, 2000) (Hart, Strawbale, 2001). "The mass comes from the masonry mortar that is used to cement the logs together, and the insulation comes from the wood itself and the central cavity between the inside and outside mortars" (Hart, Cordwood, 2001). Although the log-ends have some mass, the bulk of the thermal mass in a wall is provided by the mortar. Insulation is supplied primarily by the sawdust in the mortar joints (Chiras, 2000). Some M-I-M walls use both insulation and a vapor barrier sandwiched between the cordwood walls. This method makes for greater energy efficiency and less air infiltration (Daycreek Journal, 2008). Batt fiberglass, blown in cellulose, or an insulated sawdust mixture are also insulators used M-I-M cordwood walls. Rob Roy has found that a mixture of only vermiculite and sawdust, soaked in water overnight, results in an R-value of R-2.1 to R-2.5 per inch (Roy, Cordwood Masonry Houses, 1980). Other materials such as polystyrene or packaging peanuts have also been used for insulation infill. These materials provide a purposeful use for recycled materials.

In general, a Western red cedar log has an R-value of 1.25 per inch. In comparison, concrete has an R-value of R-0.13 per inch, stone masonry has an R-value of R-0.08 per inch, common brick has an R-value of R-0.20 per inch, and fiberglass insulation has an R-value of R-3.16 per inch (Roy, Cordwood Masonry Houses, 1980). As a rule of thumb, the greater the log depth, and subsequently the thicker the wall, the better the insulation qualities will be (Roy, Cordwood Masonry Houses, 1980).

In 1998, Pierquet et. al. conducted a study of the insulation value and embodied energy of twelve different wall types, including cordwood and straw bale. Pierquet conducted an analysis of embodied energy versus thermal performance which can be very helpful in determining the environmental friendliness of various building systems. The study finds that of the two historic vernacular building systems modeled in the study, both straw bale and cordwood construction methods required less embodied energy compared to all other wall construction methods. Pierquet's study estimated that the embodied energy of a cordwood wall is 206 Mj/odt (mega joules per oven dry tonne). In Pierquet's study, cordwood walls were found to have an R-value of R-20.5 (Pierquet, 1998). According to Daniel Chiras, the R-value for 16 inch walls ranges from R-16 to R-20, the lower value constitutes for walls built with log-ends made of dense wood such as oak and the higher value for softer woods such as cedar (Chiras, 2000, p. 178). Cliff Shockey, who lives in Saskatchewan, Canada and who knows what it's like to build houses in cold climates, has written a book called *Stackwall Construction - Double Wall Technique*. In his book, he discusses the benefits to building two cordwood walls with a vapor barrier and insulation in between. "With this technique, you can expect to gain even greater energy efficiency. Cliff states that a 24" (8" cordwood + 8" insulation + 8" cordwood) double wall has an R value of 40. Cliff's double wall technique is more time consuming and may require additional post and beam framing, but for those who want a better R-value this might be the way to go" (Daycreek Journal, 2008). This is the preferred technique for the McCall site.

Advantages of Cordwood Buildings:

- Perhaps one of the greatest advantages of cordwood construction is its potential cost (Chiras, 2000). The cost of building a cordwood house can be considerably less than a standard wood frame house (Daycreek Journal, 2008). Cost estimates for a cordwood building are as low as $10 per square foot, which make this a perfect technology for those with little money, and a lot of time, and a free wood supply (Chiras, 2000). It all depends how much of the labor you can do yourself and it depends how frugal you are in finding all of the necessary components to build the house (Daycreek Journal, 2008) (Chiras, 2000).

- Cordwood houses provide two benefits: good insulative values and thermal mass. Since the inside mortar joints are insulated from the outside wall, the mortar acts as thermal mass to keep the house at a more consistent temperature (Chiras, 2000) (Daycreek Journal, 2008).Thus, cordwood homes are relatively energy efficient. Cordwood homes tend to be warm in the winter and cool in the summer (Chiras, 2000).
- Like other alternative building technologies, cordwood homes are easy to construct and they don't take a lot of skill to build. Individual log ends are lightweight and mortaring is pretty simple to learn (Chiras, 2000) (Daycreek Journal, 2008).
- Cordwood homes use wood, which is often locally available and a renewable resource that you can "harvest" yourself, making this building technology a logical choice in many parts of the world (Chiras, 2000). Builders can also recycle glass bottles and use them in the construction of the walls (Daycreek Journal, 2008).
- Aside from being constructed from harvested wood, cordwood homes can be constructed with high-quality waste wood from discarded wooden fencing, waste from sawmills or log home builders, and peeler cores from plywood companies (Chiras, 2000).

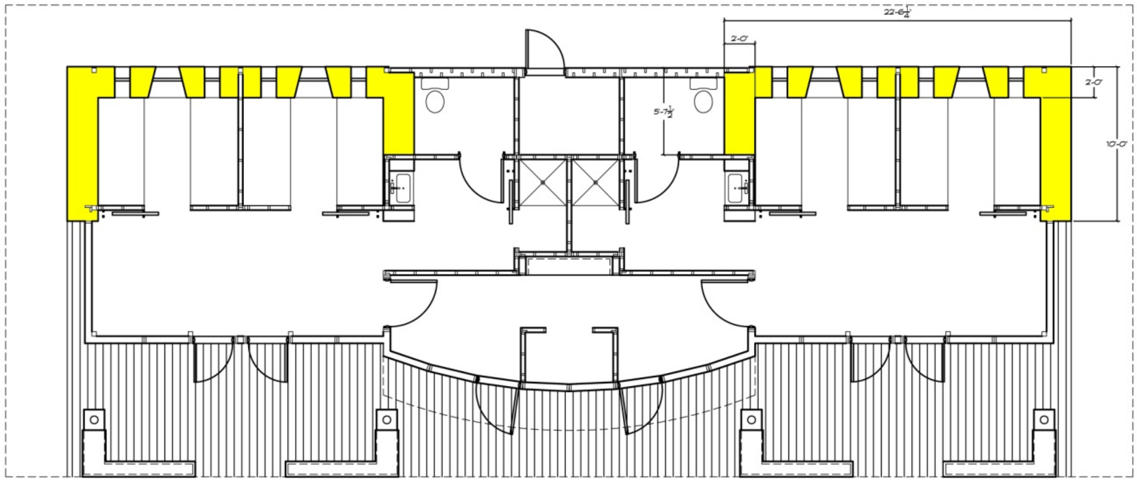
Disadvantages of Cordwood Buildings:

- Cordwood construction is extremely labor intensive. Numerous trees must be felled, cut into logs, “barked,” split, and dried prior to use. Laying up walls is also labor intensive (Chiras, 2000) (Daycreek Journal, 2008). Depending upon how much free time you have will determine how long it will take you to build. In order to save costs, you're making a trade with your time vs. your money (Daycreek Journal, 2008).

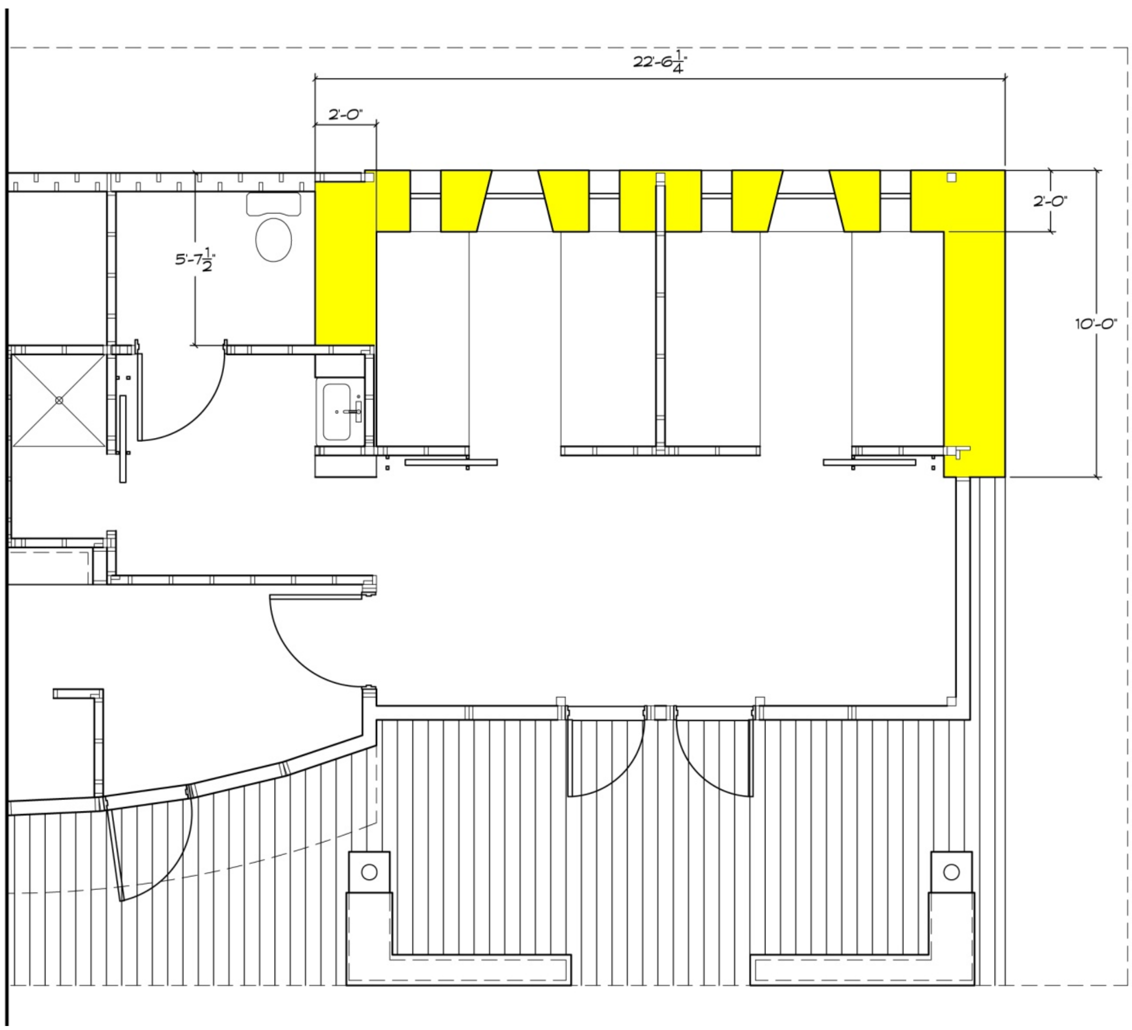
- Cordwood homes require enormous amounts of wood, especially post and beam structures (Chiras, 2000, p. 185).
- One major downside for building with cordwood is the length of time needed to dry the cordwood before construction can begin (Chiras, 2000, p. 185).
- Cordwood homes require an enormous amount of cement, which has slightly higher embodied energy than wood and earthen building materials (Chiras, 2000, p. 185).
- Enlarging or modifying a cordwood home requires special skills and training. It is difficult, for example, to knock out a new doorway unless it has been carefully planned in advance (Chiras, 2000, p. 185).
- Cordwood homes require a fair amount of maintenance, it is usually necessary to seal expansion cracks a year or two after inhabiting the building (Chiras, 2000, p. 185).

Calculating the Rough Amount of Cordwood:

Once having designed the cordwood house or structure, it is necessary to figure out how much cordwood will be needed to build it. One way to estimate the amount of cordwood needed is to figure out the total wall volume, subtract the volume of insulation infill, subtract the volume of wall space that the windows will occupy, and then divide the result by whatever percentage of wood to mortar aesthetic calls for. In this calculation, a ratio of 67% wood to 33% mortar will be used. Based on the suggestions of Cliff Shockey, who builds cordwood homes suited for cold climates, this analysis will assume a 8" cordwood + 8" insulation + 8" cordwood, double wall design (Daycreek Journal, 2008).To calculate the amount of cordwood needed, the following figures 7.3 and 7.4 will be referenced.



7.3 Guest bunkhouse floor plan. Suggested cordwood infill is highlighted. Floor plan was provided by professor Frank Jacobus.(Not to scale)



7.4 A partial guest bunkhouse floor plan illustrating the cordwood wall dimensions. Suggested cordwood infill is highlighted. Floor plan was provided by professor Frank Jacobus.(Not to scale)

Following the procedure to estimate the amount of cordwood needed, the first step is to calculate figure out the total wall volume, subtract the volume of insulation infill, subtract the volume of wall space that the windows will occupy, and then divide the result by whatever percentage of wood to mortar aesthetic calls for. In this calculation, a ratio of 66% wood to 33% mortar will be used. Assuming that the height of the walls is 8ft, the total volume of the walls for each half of the building is equal to 546ft^3. The volume of infill is approximately equal to 183ft^3. The volume of wall space that the windows will occupy is 30ft^3. Thus, the total volume of wood and mortar for each building pod is 333ft^3. Assuming that for aesthetic reasons, the walls are composed of 67% wood and 33% mortar, the wall system will consist of 223ft^3 of wood, and 110ft^3 of mortar per half of the building. Thus the total building calls for 446ft^3 of wood, and 220ft^3 of mortar. If one standard cord is equal to 128 cubic feet of stacked wood volume, then project will require approximately 3.5 cords of wood per cordwood building.

Since the McCall Field Campus is located within Ponderosa State Park, the wood needed to construct the cordwood buildings can be obtained easily from there. For wood, if 128 cubic feet is approximately equal to 4,000 pounds (weight varies depending on the type of wood and its moisture content), then 3.5 cords of wood weighs approximately 14,000 pounds or 7 tons. That being said, if one truck can carry up to one ton at a time, a minimum of seven trips will need to be made to collect the cordwood from the state park. Assuming that the truck averages a fuel efficiency of 16 miles per gallon, and the average round trip is 6 miles within the peninsula to collect the wood, the carbon costs of transporting the cordwood to the field campus is 51.36 pounds of CO_2. It is ecologically convenient to have the source of cordwood and the construction site in close proximity to each other (Daycreek Journal, 2008).

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Chapter 8: Feasibility Assessment of Rammed Earth Construction

Rammed Earth History:

Rammed earth is an ancient earth building technique that has been used around the globe for millennia in a wide range of climatic conditions, from wet northern Europe to dry regions in Africa (Soledad Canyon Earth Builders, 2008). Evidence of the early use of rammed earth as been seen in Neolithic archaeological sites of the Yangshao culture and the Longshan culture in China along the Yellow River dating back to 5000 BCE. By 2000 BCE, the use of rammed earth architectural techniques was commonly used for walls and foundations in China (Xujie, 2002). In the United States in the 1800’s, rammed earth was popularized by a book *Rural Economy* by S. W. Johnson (Soledad Canyon Earth Builders, 2008). For example, it was used to construct Borough House Plantation and Church of the Holy Cross in South Carolina, which are two National Historic Landmarks of the United States (Cassell, 2003). Rammed earth homes and buildings built in the late 1700's and early 1800's can still be found throughout the United States (Soledad Canyon Earth Builders, 2008).

By its very nature, earth is one of the best sustainable building materials as it is historically, the longest used material by man (Soledad Canyon Earth Builders, 2008). It is a naturally available product universally, with a heavy thermal mass and a natural barrier to cold winds and forces of nature including insects and rodents (Chiras, 2000). The material is not rationed or monopolized, it is fire proof, and sound proof (Cassell, 2003). Rammed earth can contribute to a solution for today’s ecological dilemma caused by deforestation and toxic building materials (Chiras, 2000).

Rammed earth structures are beneficial for natural building because they can utilize locally available materials with little embodied energy and harmful waste (Chiras, 2000). Earth is a widely available building material with virtually no side effects associated with harvesting for use in construction (Sustainable Sources, 2008). The earth used in rammed earth construction is typically subsoil, leaving topsoil readily available for agricultural uses (Chiras, 2000). Often the soil can be used on the site where the construction takes place, thus reducing cost and energy used for transportation (Cassell, 2003). It is also affordable to build with, as the materials are inexpensive or free. It is a viable building material for low income builders. Today more than 30% of the world's population uses earth as a building material (Cassell, 2003).

Rammed Earth Specifications:

Rammed earth is a modern, eco-friendly masonry wall made from a carefully controlled mix of aggregates such as graded sub-soil, quarry waste or recycled crushed demolition waste (Hall, M.R., 2007). Rammed earth construction's main advantages are that it can provide "temperature and relative humidity buffering reducing the enthalpy of indoor living spaces whilst saving operation energy costs and associated emissions, and it provides a low-carbon alternative to fired clay bricks using locally available raw materials" (Hall, M. and Allinson, D., 2008). Rammed earth construction involves dynamically compacting of carefully graded moist sub-soil between removable forms to create a compressed earth wall that is both strong and durable. The walls are free-standing and load bearing (Hall, M., and Djerbib, Y., 2004).

Over time, the earthen mix that seems to have worked best consists of 70% sand and aggregate (small stone or gravel) and 30% clay, which acts as a binder. The clay is a substance that essentially cements all of the other particles together (Chiras, 2000, p. 44). The correct clay to use must be nonexpansive, meaning that it that does not expand when wet and then crack when it dries. The earth used for making rammed earth buildings generally refers to a sandy loam sub-soil. Topsoil is unsuitable to use due mainly to the significant amount of organic matter present that biodegrades, absorbs water, and is highly compressible (Hall, M., and Djerbib, Y., 2004). If the clay used in the soil mix is not adequately broken into the smallest particles possible during mixing, soft lumps will remain in the mix. Interspersed in the otherwise solid earthen matrix, clay lumps can substantially weaken earthen walls, so much so that some builders won't use soil if it has any clay in it at all; they insist on using cement stabilizers (Chiras, 2000, p. 46). In places where moisture and earthquakes are a problem, or where building codes require it, Portland cement is added in small amounts of 3% to 12% by volume. Adding cement renders a wall more water resistant and increases its comprehensive strength and longevity (Chiras, 2000, p. 44).

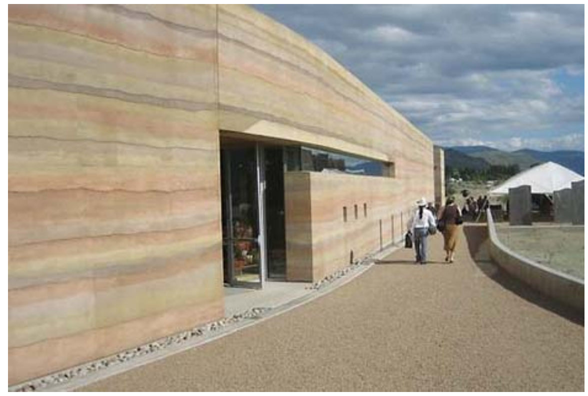
The use of Portland cement as a stabilizer helps to reduce plastic behavior, swelling, cracking, and strength loss of the structure, and serves to address durability issues under partially or fully saturated conditions (Hall, M. and Allinson, D., 2008). The resultant wall material can therefore be classed as a weakly hydraulically-bound unfired earthen material typically containing hygroscopic clay minerals usually exhibiting a high density and a low void ratio (Hall, M. and Allinson, D., 2008). However the use of cement is contentious as its manufacture contributes to manmade carbon emissions.

After the proper soil mix is reached, the soil is delivered to the forms until they are filled to a depth of 7.5" to 8". The soil is then tramped down to a depth of 4.5"to 5" (Chiras, 2000, p. 50) (Soledad Canyon Earth Builders, 2008). After compressing the earth the wall frames can be immediately removed and the walls require an extent of warm dry days after construction to dry and harden. The walls are immediately load bearing and can either be designed to be solid or to have insulated-cavity (Hall, M.R., 2007). The structure can take up to two years to completely cure, and the more it cures the stronger the structure becomes (Chiras, 2000) (Cassell, 2003). Rammed earth hardens like stone and has a uniquely attractive, layered appearance that closely resembles natural sandstone (Hall, M.R., 2007). Any blemishes made to the building can also be patched up using the soil mixture as a plaster and sanded smooth (Chiras, 2000). The thickness of a typical rammed earth wall is 18" to 24". The amount of earthen material required to build a 2,000 square foot home out of rammed earth is 200 tons. Rammed earth walls weigh about 2 tons per running foot. An 18 inch thick wall can safely run 18 feet high (Chiras, 2000, p. 52). Rammed earth is durable, and weather resistant. Any exposed walls may be sealed to prevent water damage, there are several proprietary products specifically designed to seal earth walls. For instance, walls can be coated with stucco for further protection (Chiras, 2000, p. 34).

Other important things to know about rammed earth are prior to construction, one will need to know the depth of the frost line, that is, how deep the soil freezes. This information permits the designer to determine how deep a foundation must be to avoid frost heave. Yet the deeper the foundation, the more steel reinforcing that is required (Chiras, 2000, p. 40). Also, rammed earth walls need not always be exposed, aside from being stuccoed over for protection or aesthetic reasons, rammed earth walls may be placed within the weatherproof fabric of the building. Depending on external climate and weather conditions, walls may have external insulation, soft plaster, timber cladding or a number of locally specific finishes which are typically applied to masonry buildings.

Rammed earth is not only an economically viable construction technique, it results in pleasant, and energy-efficient buildings. The density and thickness of rammed earth makes it so that hot or cold temperature penetration has a slow rate of thermal conductivity. Warmth takes almost 12 hours to work its way through a 14 inch thick wall (Cassell, 2003). Rammed earth also allows more air exchange than concrete structures allowing the building to breathe and not become clammy without significant heat loss as the material mass absorbs the temperature as the wall breathes (Cassell, 2003).

8.1 Interior photo of curving earth wall and glass work. The building was constructed by Terra Firma. Portfolio Photo by Terra Firma (Terra Firma Builders Ltd., 2007).



8.2 The Nk'Mip Desert Cultural Center, a stunning Rammed Earth structure by Hotson Bakker Bonifacr Haden Architects. Photo by John Barrie (Barrie, 2007).

Rammed Earth Issues to Consider:

One main issue to consider with rammed earth is moisture. According to Hall (2006), the entry of moisture into the external envelope of a rammed earth building can be caused by a number of different mechanisms primarily wind-driven rainfall, condensation, infiltration and absorption from the surrounding ground, and from general building use. Moisture ingress in rammed earth walls can also be caused by capillary suction, gravity, surface tension, and hydrostatic pressure (Hall, M. and Djerbib, Y., 2006). Physically, water can cause rammed earth buildings many problems such as water staining, damage to internal finishes, damage caused by cyclic wetting and drying, fracturing instigated by dimensional fluctuations and exacerbated by fatigue loading, the rotting of lintels, window and door frames, freeze/thaw damage of saturated masonry, decreased thermal performance and efficiency, uncomfortable and unhealthy ambient air conditions inside the affected building, and electrical installations can be damaged and/or rendered unsafe for use. Chemically, water can cause rammed earth buildings many problems such as the loss of adhesion between binding agents and aggregates, a sulphate attack of Ordinary Portland cement (if Portland cement was used in the project), the efflorescence (re-crystallization of soluble salt species as surface deposits) and the, corrosion of metals such as steel reinforcement, conduits (Hall, M. and Djerbib, Y., 2006).

Embodied Energy and Insulation Values:

Generally in traditional buildings, thermal comfort has been achieved at the expense of significant energy use for heating and cooling. However, a well-designed rammed earth building should be able to provide good thermal comfort, while simultaneously having low energy consumption. (Taylor, 2008). Rammed earth walls naturally have a high thermal mass. Thermal mass refers to any material that absorbs heat, either from sunlight striking it or by being in contact with warm air (Chiras, 2000, p. 56). Thermal mass heats up slowly during the day and releases its heat during the evening. Yet the suitability of rammed earth in cold climates is somewhat uncertain. Some builders advise against the use of rammed earth in cold climates because the thick earthen walls provide surprisingly little insulation. In fact, an inch of rammed earth has an R-value of only R-0.25. Therefore, an 18" rammed earth wall has an R-value of R-4.5, not much better than double pane, low E-glass. One solution is to build thicker walls. The mass will absorb heat and radiate it back into the room. Another solution is to add rigid foam insulation to the wall system with a fairly high R-value (Chiras, 2000, p. 58). As a side note, the thickness and density of rammed earth walls lends itself naturally to soundproofing and the earthen materials used in the walls make them virtually fireproof (Chiras, 2000).

Advantages of Rammed Earth Buildings:

- Rammed earth homes use local materials, reducing our impact on the planet (Chiras, 2000, p. 62).

- Building homes with earthen walls reduce our demand for lumber and helps protect forests. (Chiras, 2000, p. 62).
- Rammed earth homes lend themselves to passive solar design (Chiras, 2000, p. 62).
- In many climates, these homes are energy efficient and thus reduce our dependence of fossil fuels, which reduces air pollution and other impacts associated with the production, transportation, and consumption of fossil fuels (Chiras, 2000, p. 62).
- Rammed earth walls are very strong and capable of resisting earthquakes, hurricanes, and tornadoes (Chiras, 2000, p. 62).
- Rammed earth walls are resistant to decay. If well designed and properly built, they can outlast wood-frame structures, which deteriorate over time and need serious renovation after 50 to 75 years (Chiras, 2000, p. 62).
- Rammed earth walls are safe in fires. In fact, fire hardens and strengthens the exterior walls (Chiras, 2000, p. 62).
- The thick walls of rammed earth are soundproof, a benefit of immense value in this increasingly noisy world (Chiras, 2000, p. 62).
- Rammed earth walls are impenetrable to insects and rodents, unlike standard wood-frame homes (Chiras, 2000, p. 62).
- Rammed earth building technology may be less expensive than brick, stone, adobe, and even ferro-cement construction (Chiras, 2000, p. 62).

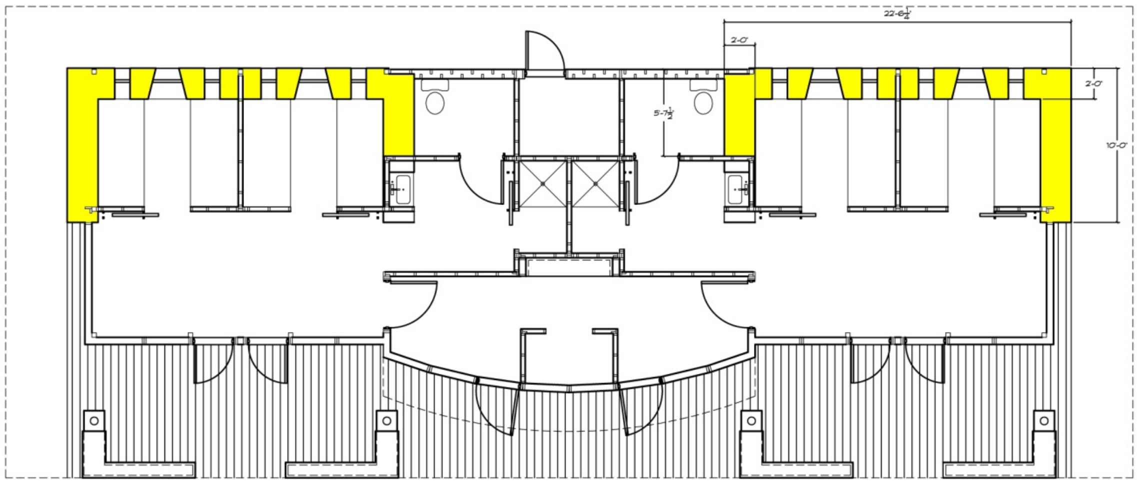
Disadvantages of Rammed Earth Buildings:

- Building rammed earth walls, while magical, is very hard work (Chiras, 2000, p. 63).
- Rammed earth construction requires careful analysis of soils. Without it, costly errors can be made (Chiras, 2000, p. 63).

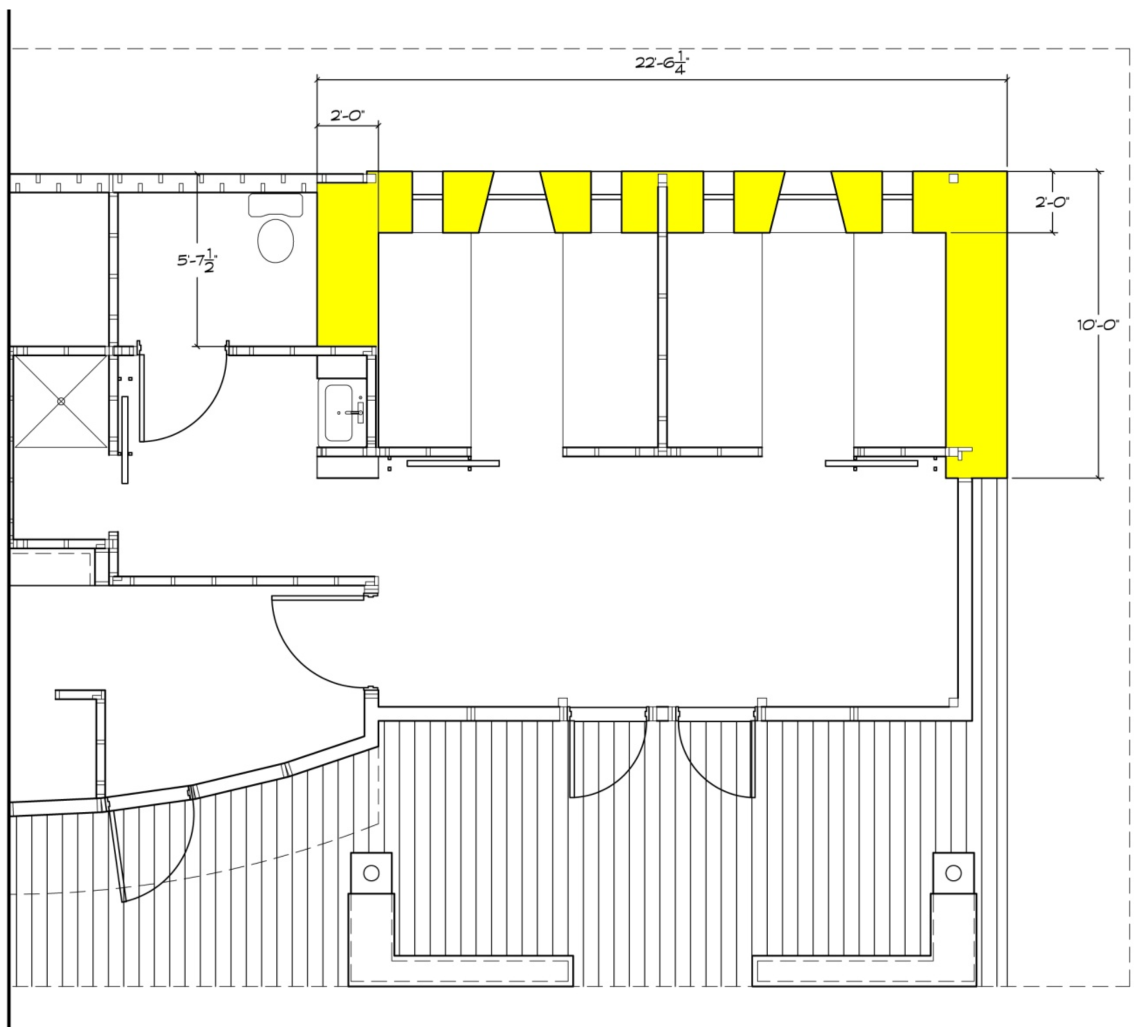
- On-site mixing, wetting, and compacting of soil requires careful attention to detail. Mistakes are difficult, if not impossible to repair once a wall has hardened (Chiras, 2000, p. 63).
- Rammed earth building requires special skills in form construction to make walls, windows, doors, and niches (Chiras, 2000, p. 63).
- Rammed earth construction is not widely understood, creating barriers to its acceptance, especially by other builders, homeowners' associations, and building departments (Chiras, 2000, p. 63).
- Rammed earth homes require a lot of wood to build forms, although some wood can be reused after the form work has been completed (Chiras, 2000, p. 63).
- Rammed earth construction is best conducted by contractors and not generally well suited for owner-builders. Contractors can use the same forms over and over again, saving money and resources (Chiras, 2000, p. 63).

Calculating the Rough Amount of Rammed Earth:

Once having designed the rammed earth house or structure, it is necessary to figure out how much rammed earth will be needed to build it. One way to estimate the amount of rammed earth needed is to figure out the total wall volume, subtract the volume of wall space that the windows (and doors if applicable) will occupy. To calculate the amount of rammed earth needed, the following figures 8.3 and 8.4 will be referenced.



8.3 Guest bunkhouse floor plan. Suggested rammed earth infill is highlighted. Floor plan was provided by professor Frank Jacobus.(Not to scale)



8.4 A partial guest bunkhouse floor plan illustrating the rammed earth wall dimensions. Suggested rammed earth infill is highlighted. Floor plan was provided by professor Frank Jacobus.(Not to scale)

Following the procedure to estimate the amount of rammed earth needed, the first step is to calculate figure out the total wall volume, and then subtract the volume of wall space that the windows will occupy. Assuming that the height of the walls is 8ft, the total volume of the walls for each half of the building is equal to 546ft^3. The volume of wall space that the windows will occupy is 30ft^3. Thus, the total volume of rammed earth needed for each building pod is 516ft^3. That said, the amount of rammed earth needed per building is 49,030lbs or 24.51 tons (Gershtein, 2005). At this point in the project, no local suppliers of the materials required to produce a rammed earth building in McCall have been identified. The nearest potential supplier has been located in Portland, Oregon. Rammed earth construction also requires professional assistance to construct which will increase costs, it has much lower insulation values, and if no local suppliers can be identified, the carbon costs of using rammed earth at the Environmental Learning Center is much higher than using straw bale or cordwood. In general, the use of rammed earth in McCall requires further study for feasibility. There has not been a soil analysis to identify whether the local soil is suitable. Also, for this climate an R-30 wall is needed, thus an insulation system will be required to use in conjunction with the rammed earth wall.

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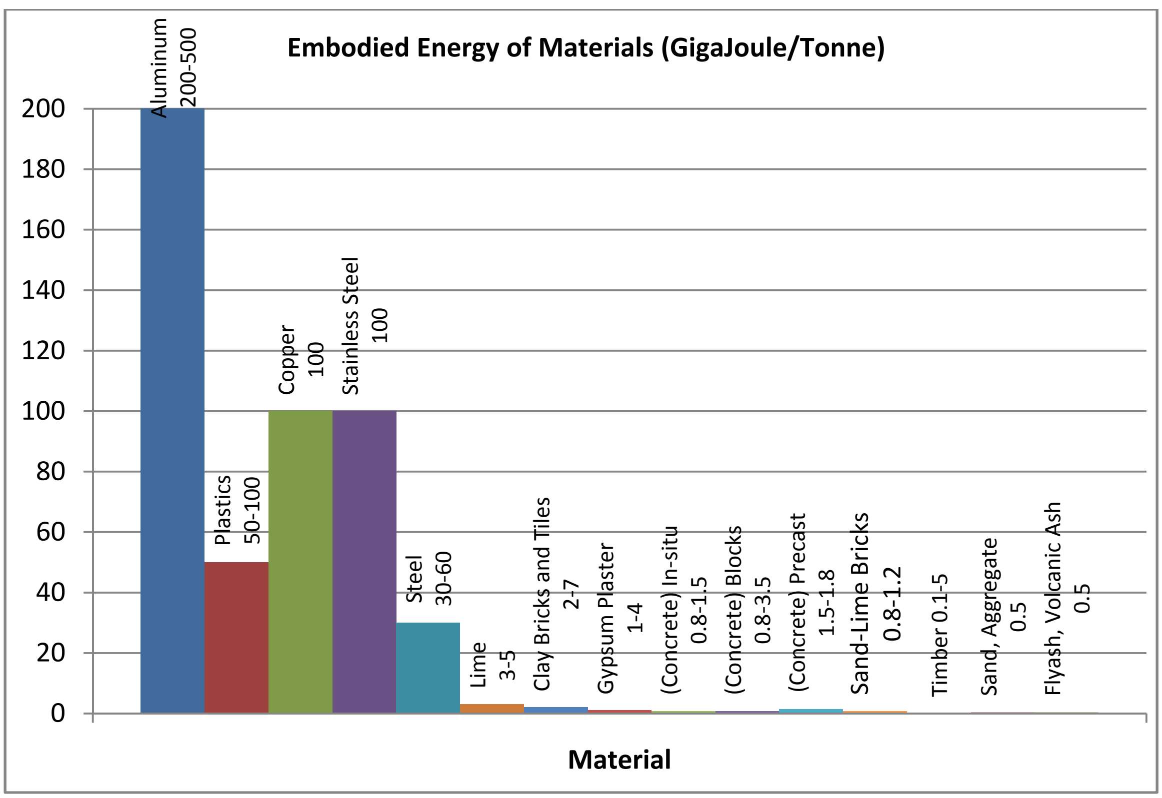
Chapter 9: A Discussion of Embodied Energy and Materials

Embodied Energy of Materials:

The study of embodied energy allows for an understanding of how much energy is used in the construction of buildings and the cost benefits of recycling. Embodied energy is the energy needed for procuring raw materials, manufacture, transport, construction, maintenance and repair (Sartori, 2007)(Recovery Insulation, 2005). The total amount of energy needed for most building products can be high, typically accounting for 20% of the building's energy use during a 50-year life cycle, the equivalent of 10 to 20 times the annual energy use. Reducing embodied energy can reduce the overall environmental burden of a building (Recovery Insulation, 2005).

Buildings are high consumers of energy and therefore have a significant impact on our environment (Recovery Insulation, 2005). Buildings demand energy in their life cycle, both directly and indirectly. Directly for their construction, and operation (known as operating energy), their rehabilitation, and eventually their demolition; indirectly buildings consume energy through the production and transportation of the materials they are made of (Sartori, 2007). The United States' building sector is the leading producer of carbon emissions and leading consumer of energy (Architecture 2030, 2006-2008). When the energy used in construction materials, building usage, and maintenance of commercial and residential buildings is taken into account, the building sector accounts for almost half of the United States' energy consumption and tops the list in production of carbon emissions (Architecture 2030, 2006-2008) (Morela, 2001). An important goal for the building sector should be to produce buildings that have a minimum environmental impact. Energy use in buildings is a central issue due to the fact that energy is generally one of the most important resources used in a building over its lifetime (Thormark, 2002). Low energy buildings have therefore become an important research field (Thormark, 2002). "Low-energy building" refers to a building built according to special design criteria aimed at minimizing the building's operating energy (Sartori, 2007).

The embodied energy per unit mass of materials used in a building varies enormously from about two gigajoules per tonne for concrete, to hundreds of gigajoules per tonne for aluminum, as illustrated in graph 9.1. Cement and aluminum are higher than average and glass is lower. On average, 0.098 tonnes, or 216.05 pounds of CO_2 are produced per gigajoule of embodied energy (Recovery Insulation, 2005).



9.1 This graph illustrates the embodied energy of different materials. It is highly obvious that metals such as aluminum, copper, and stainless steel require the most amount of energy to produce. Plastics are the next largest consumer of energy (Harvey, 2006).

Using these values alone to determine preferred materials is inappropriate because of the differing lifetimes of materials, differing quantities of a material required to perform the same task, and different building and construction design requirements (Recovery Insulation, 2005). Taking into consideration the value of using salvaged and recycled materials is important to think about as well. There are several reasons to include the aspects of recycling in an analysis of the energy use of buildings.

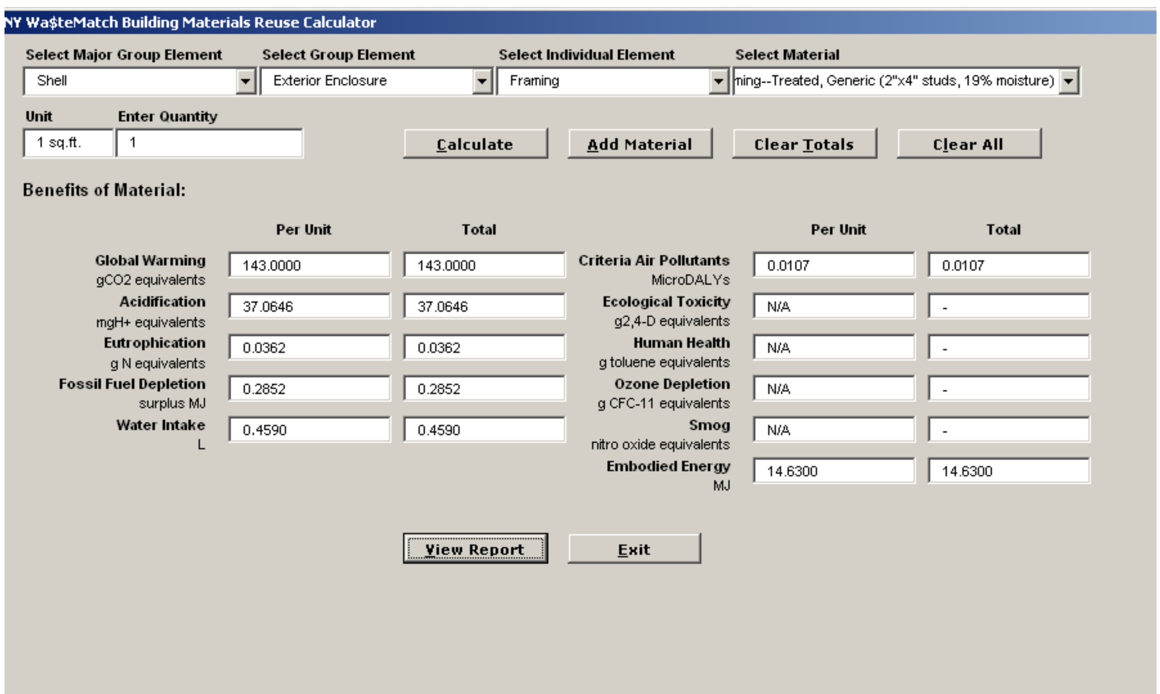
> "In a study of recycling nationally produced building waste, the potential energy saving through recycling was about 50% of the embodied energy. (Embodied energy for the waste was calculated as if the waste would have been new building materials produced today.) In a study of new buildings, the recycling potential was about 50% of the embodied energy. When reused materials were used in a one-family building, the embodied energy decreased about 45%" (Thormark, 2002).

The salvaging or recycling of building materials commonly saves about 95% of embodied energy which would otherwise be wasted. Some materials such as bricks and tiles suffer damage losses up to 30% in reuse (Recovery Insulation, 2005). The savings by recycling of materials for reprocessing varies considerably with savings up to 95% for aluminum but only 5% to 20% for glass. Some reprocessing may use more energy, particularly if long transport distances are involved. (Recovery Insulation, 2005). Chart 9.2 shows the amount of energy that can be saved by recycling materials. It is obvious that aluminum has the highest potential energy savings, glass has the lowest due to the fact that glass requires a substantial amount of reprocessing to be reused.

Chart 9.2 The potential production energy savings of recycled materials (Mumma, 1995).

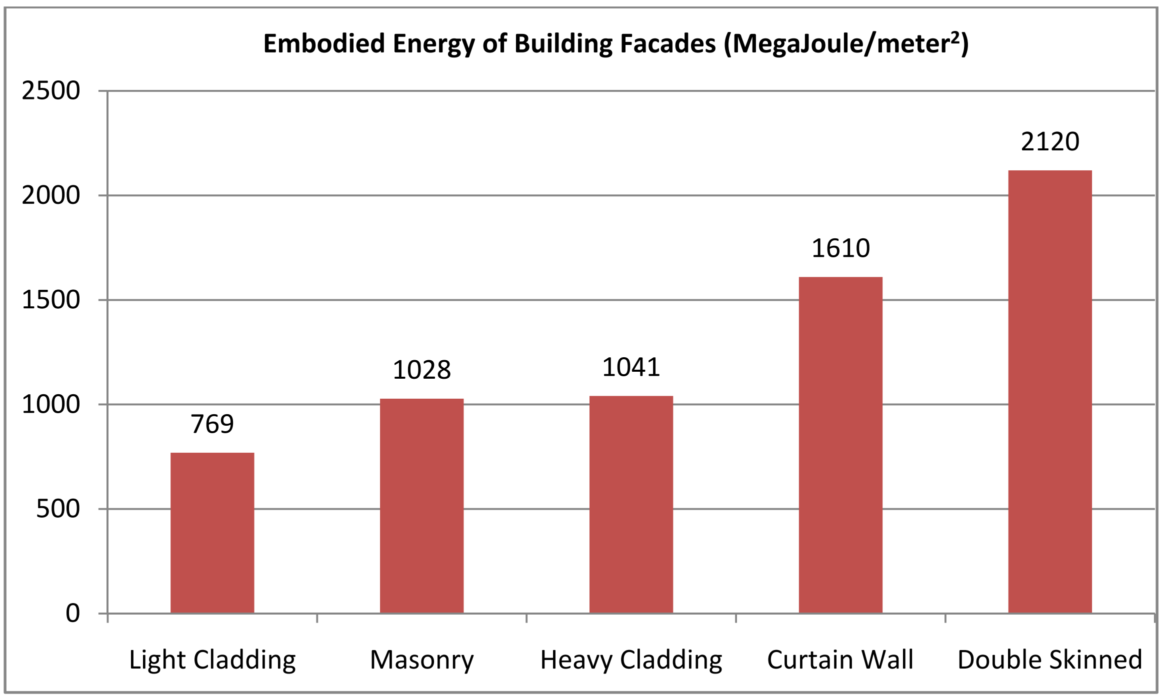
	Energy required to produce product from virgin material (million BTU/ton)	Energy saved by using recycled materials
Aluminum	250	95%
Plastics	98	88%
Newsprint	29.8	34%
Corrugated Cardboard	26.5	24%
Glass	15.6	5%

Luckily for builders, there are tools which can help match builders seeking materials with suppliers of old materials that they are wishing to discard. **NY Wa$teMatch**, is New York City's materials exchange and solid waste reduction program. NY Wa$teMatch provides reuse, recycling, and other innovative waste solutions to boost a builder's bottom line. NY Wa$teMatch helps clients to reduce disposal costs, generate revenue, and obtain raw materials for free (NY Wa$teMatch, 2007). NY Wa$teMatch provides a very handy "Materials Reuse Calculator" EXCEL macro on their website for helping builders to understand how much embodied energy and carbon they are saving by using salvaged materials. Photo 9.3 is a screen shot of the materials reuse calculator.



9.3 This is a screen shot of the NY Wa$teMatch "Materials Reuse Calculator" EXCEL macro (NY Wa$teMatch, 2007).

Another topic to consider when thinking about what materials to use for a building is the building's energy efficiency and how external cladding affects the building's energy use. Making buildings more energy efficient through the use of a tighter, more insulative building envelope usually requires more embodied energy (Recovery Insulation, 2005). Graph 9.4 shows the different embodied energy costs for several different building facades. The simpler, lighter clad buildings generally have a lower embodied energy value in total and per unit floor area, due to fewer materials being used in construction and lower embodied energy coefficients for those materials. Embodied energy of houses ranges from about 4.5 GJ/m^2 to 5.5 GJ/m^2 mainly depending on floor type, material of cladding and number of storeys (Recovery Insulation, 2005).



9.4 This chart illustrates the embodied energy of sample building facades. The more insulative the façade, generally the lower the building's operational energy use is, yet the more the embodied energy it takes to produce the building (Harvey, 2006).

Construction Materials Discussion:

The choices made regarding a building's materials, and design principles, have a significant, but previously unrecognized impact on the energy required to construct a building. Embodied energy is one measure of the environmental impact of building materials, construction, and the effectiveness of reusing materials, particularly CO_2 emissions. (Recovery Insulation, 2005). In choosing between alternative building materials on the basis of embodied energy, not only should the initial materials be considered, but also the transportation of the materials, the materials consumed over the life of the building during maintenance, repair and replacement (Recovery Insulation, 2005).

This is why in this feasibility analysis for the Carbon Neutral Environmental Learning Center, local suppliers of materials were identified so that the transportation carbon costs of using the selected materials could be assessed. It was found that to build one guest bunkhouse using straw bale construction 1,712 pounds of CO_2 would be emitted into the atmosphere due just to transportation. That's almost one ton of carbon for only one building just for getting the materials to the site! It was found that each straw bale used would have a carbon cost of 10.32 pounds of CO_2. On a positive note, straw bale construction is highly insulative which should significantly reduce the energy demands of the building over the course of its lifetime.

Cordwood construction, on the other hand, would prove to have a far less carbon cost to use for this project. Since the McCall Field Campus is located within Ponderosa State Park, the wood needed to construct the cordwood buildings can easily be obtained from there. For wood, if 128 cubic feet is approximately equal to 4,000 pounds (weight varies depending on the type of wood and its moisture content), then the 3.5 cords of wood needed to construct one building weighs approximately 14,000 pounds or 7 tons. That being said, if one truck can carry up to one ton (2,000 pounds) at a time, a minimum of seven trips will need to be made to collect the cordwood from the state park. Since the field campus is located within the Ponderosa State Park, the carbon costs of transporting the cordwood to the field campus are a mere 51.36 pounds of CO_2. It is ecologically convenient to have the source of cordwood and the construction site in close proximity to each other (Daycreek Journal, 2008). The mortar and insulative infill for a cordwood building have varying carbon costs. The suggested mortar mix to use is 9 parts sand, 3 parts sawdust, 3 parts builder's lime, and 2 parts Portland cement. All of these materials can be easily and locally obtained except perhaps for the builder's lime and Portland cement. Portland cement is also known to have a high carbon cost, or high embodied energy value, since it takes a large amount of energy to produce it and to transport it. Not only is cordwood easily available, cordwood also provides another benefit of carbon sequestration. Wood and wood products contain stored carbon which is locked up in the material until eventual release through mechanisms such as burning, bacterial or fungal decay, or consumption by insects (Buchanana, 1999).

In regards to rammed earth construction, not much at this point can be calculated in regards to its carbon cost. It is known that 516ft^3 of earth mix will be needed, which is equivalent to the amount of rammed earth needed per building is 49,030lbs or 24.51 tons (Gershtein, 2005) of material, but no suppliers have yet been identified in the local area. The nearest potential supplier has been located in Portland Oregon. In this climate which receives a heavy amount of snow in the winter, it is likely that Portland cement will need to be added to the mixture for strength and water resistance. Rammed earth buildings also have an insulative R-value of only R-4.5 for an 18" rammed earth wall, which is not much more insulating than double pane, low E-glass. Insulation will undoubtedly need to be used for a rammed earth building in this climate. One positive aspect of rammed earth is its thermal mass which acts to absorb heat, either from sunlight striking it or by being in contact with warm air (Chiras, 2000, p. 56) during the day and then releases its heat during the evening.

Since this thesis is being written concurrently as the first building to be built on the site in 2009 is still being designed, it is nearly impossible to speculate on the carbon or embodied energy costs of the other building materials to be used in the construction of the building to be built this summer. It has been proposed that the building will use either double or triple pane windows in order to retard thermal transmission through the building envelope. Composting toilets, as seen at IslandWood, are also being considered. On a positive note, this thesis has been able to estimate the amounts of straw bale, cordwood, and rammed earth material needed, the general carbon costs of the material transportation, and the carbon costs of using the material (except for rammed earth). It is obvious that the use of straw bale has a significantly high carbon cost compared to cordwood, but the building to be constructed this summer will be utilizing straw bale due primarily to the fact that the time constraints of drying cordwood will not permit a cordwood building to be constructed in such a short time frame. None the less, it is one of the goals for the Carbon Neutral Environmental Learning Center to demonstrate the use of alternative building materials, so it is almost certain that both cordwood and rammed earth guest buildings will be constructed in the near future. This thesis has served to illustrate the pros and cons of these three building materials and will help aid in the design and construction decisions of future buildings to be built for the Environmental Learning Center.

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