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Traditional building materials and the sustainability of the Cheyenne and Arapaho Tribal College design

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Traditional building materials and the sustainability of the Cheyenne and Arapaho
Tribal College design

by

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Introduction

Spiderwoman told us, if we take care of the Earth, the Earth will take care of us.

- Tantoo Cardinal (McLeod, 2002)

In decades past, the word sustainability was associated with economic growth, efficient allocation of resources, and financial stability. As long as the economy was growing and resources were being exploited, companies and citizens were making money. In other words, sustainability referred to sustained economic growth. Sustainable economic growth is defined as “an increase in through-put, which is the flow of natural resources from the environment, through the economy, and back to the environment as waste” (Daly, 2011, p.6). The unfortunate consequences of such sustained growth include resource scarcity and depletion; natural habitat destruction; air, water and land pollution; and the fact that human activity is outpacing the ability of the Earth to renew itself. “This kind of growth, of course, cannot continue indefinitely, as the Earth and its resources are not infinite. While growth must end, this in no way implies an end to development, which we define as a qualitative change or realization of potential” (Daly, 2011, p.6). Human beings stop growing physically at a certain point in life, yet a qualitative change can continue as a person develops his or her potential by studying, travelling, and gaining experience.

The contemporary understanding of “sustainability” is complex and often difficult to define, as it can be applied to economics, culture and ecosystems. The term became widely used in its present sense in 1987, after it appeared in a UN report by Norway’s former prime minister Gro Harlem Brundtland, who defined sustainable development as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (Werbach 2009) – which takes the ecological point-of-view. More recently, as Michael Pollan, the author of *The Omnivore’s Dilemma*, writes, the whole idea of sustainability has been “in danger of floating away on a sea of inoffensiveness. Everybody is for it - whatever ‘it’ means” (Werbach 2009). Instead of focusing on economic activity and ignoring everything else, the focus of sustainability is shifting to the concept of gently using virgin resources and waste sinks in a manner that allows for ample regeneration. It is part of the present-day vocabulary in architecture firms and schools and yet there are few building

projects that truly incorporate the idea of sustainability. This thesis shows that through design, both ecological and cultural sustainability can be achieved in a building project while stimulating development and potential within a community.

Most Native American tribal cultures' world views include people in relationship with nature or their ecosystem around them rather than the western view of being separate, outside and over (stewards or overseers) the world of plants and animals around them (par Paxson, 2010). The western view sees the world as resources to be used for and by people whereas the Indigenous view does not. Therefore, Native American Tribes understood the need to work with the materials that were readily available and indigenous to a specific location – limited to what humans and the animals they domesticated were able to carry across a reasonable distance. Respecting the Earth and the vast resources it provided meant responding to climate and place while wasting nothing (par. Wildcat, 2009). The Plains Indians, for example, were hunters of buffalo. They were strategic in deciding which animal or animals to pursue, knowing that leaving the heard relatively intact would ensure the sustainability of the herd. They also took care to utilize every part of the buffalo from the meat to the bones to the hide. When setting up dwelling, they responded to the climate with strategies to maximize heat in the winter months and to shade against heat gain in the summer months (par. Paxson, 2010).

European settlers, on the other hand, saw the North American continent as a land with vast and limitless resources to be exploited. Since the invention of mechanical heating and air conditioning, the built environment has responded less to location, climate and place. These buildings are devouring energy at a pace that is out of control. "According to the U.S. Energy Information Administration (EIA), the building sector consumes nearly half (49%) of all energy produced in the United States. Seventy-seven percent (77%) of all the electricity produced in the U.S. is used just to operate buildings" (Mazria 2011). Suddenly, mainstream culture has begun to worry about carbon dioxide emissions, ozone depletion and the loss of precious rainforests – conditions that a lust for energy has created. One of the perils of technology is that humans have a belief that technology can solve these problems. Instead of looking back to the passive strategies of indigenous people, western society looks to yet-to-be-invented technology to "save" the world. The built environment is no different. New and innovative technologies are being incorporated into buildings as rapidly as they are conceived (i.e. photovoltaic panels, computerized lighting controls), all

the while focusing solely on energy conservation rather than energy production, new materials instead of renewable ones, and a commissioning strategy based on spending rather than conserving. This project will take a tangential approach to traditional western methods and strategies for saving energy – simply by not utilizing it in the first place.

Native Americans' world view resulted in what westerners perceive as living off the land gently with knowledge of the need for regeneration to continuously meet their basic needs. They know the true concept of sustainability. This knowledge has been passed down for thousands of years and yet dominant culture is just now beginning to take notice (par. Wildcat, 2009). In the zeal to exploit what was perceived as limitless resources in a vast new land, European settlers not only put these resources to use, but pushed aside the very cultures within whom the knowledge of these resources exists. As the Indigenous peoples were increasingly pushed aside, maintaining certain aspects of their traditional way of life – the ability to sustain themselves in their deep-rooted traditional beliefs became difficult or impossible (par. Paxson, 2010). Cultural sustainability is critical for the survival of the human spirit, just as water is critical for the survival of the human body. Yet when the word sustainability is uttered, it immediately evokes visions of green grass, clear skies and hippies hugging trees. What is missed is the broader definition of the word which is to continue without end or interruption.

The proposed design for the Cheyenne and Arapaho Tribal College (CATC) (see Appendix C) brings cultural and ecological sustainability together through a particular architectural design approach, thus bringing back architecture of particularity to the region of Western Oklahoma. It responds to the area, its climate and its people by taking into account the Tribe's culture, the climate, and their desire to maintain their way of life through education. Therefore, their college campus must be fully sustainable by incorporating culture, building design and orientation, passive energy strategies, building mechanical systems, and a major focus on proper material selection, bringing these aspects together into a recipe for designing and constructing a truly sustainable work of architecture.

The cultural aspect of the design, as well as the history and traditions of Cheyenne and Arapaho spirituality, community and education are researched through both written and oral accounts of the Tribe's past and present condition. The design strategy then focuses

on the climate the tribal college is intended to occupy – including the cultural, contextual, educational, and meteorological climates.

The major focus of this design recipe is based on the most important ingredient for creating buildings – the materials specified to construct the project. Research on these materials has been conducted by examining the embodied energy and environmental impact of the extraction of the material from the natural resource base, the manufacturing or refining of the material, and the transportation of the material between locations and ultimately to the construction site. In addition, each material has been examined for its relevance, longevity, future availability, and eventual and inevitable replacement. Each material will then be rated on its ability to be recycled, reused, or discarded when its usefulness as a building material comes to an end. The systems and materials are matched to produce a result which proves to be practically benign in terms of energy consumption and ecological impact.

Finally, as any successful community building project should do, the possibilities for community development and growth are outlined. Community and economic development within the Cheyenne and Arapaho Tribe is dependent upon the education and empowerment of their citizens. The existence of the Tribal College and the educational opportunities it provides will lead to significant developments in the community. A handful of possibilities, which are theoretically endless, are offered as a result of the opportunities that will be unlocked because of the Tribal College.

1 The Cheyenne and Arapaho Tribes of Oklahoma

1.1 Introduction

The Cheyenne and Arapaho Tribes of Oklahoma are joined as one tribal government in Western Oklahoma. Although the two Tribes have been administratively joined by the U.S. Government since the nineteenth century, each maintains a distinct culture and language. According to the 2009 Cheyenne and Arapaho Base Report, as of March 2009, tribal enrollment included 12,232 members for the combined Cheyenne and Arapaho Tribes, of which 4,876 reside within nine counties of Western Oklahoma that encompass the Cheyenne and Arapaho Nation. The two tribes originally resided on a 5 million acre reservation that has since been broken up by the federal government into allotments. "An Act of March 3, 1891, divided the Cheyenne-Arapaho land into 160-acre parcels. The remainder was sold to white homesteaders" (Hoig 2006, p.96). Because of this, the Cheyenne and Arapaho do not have a reservation as such - instead they live on trust land that is scattered throughout this nine-county area.

Due to the passage of the Self Determination Act by Congress in 1975, the Cheyenne and Arapaho have either internalized or contracted most of the programs that were formerly overseen by the federal and state governments. As a result they now employ more tribal members and operate the programs in a manner that is more "in sync" with traditional tribal values. The Cheyenne and Arapaho Business Committee attempts to create as many jobs as possible and yet unemployment, according to the Bureau of Indian Affairs 2005 Labor Force Report, shows a Cheyenne and Arapaho unemployment rate of 70% (Base Report, 2009). In addition, 24% of employed families have income below the poverty level, which is considerably higher than the current national average.

1.2 The Spirituality of the Cheyenne

The Supreme Being created the universe and all life out of nothing; this act was perceived differently by culturally distinct peoples as they evolved their unique ways of life and world views. Creation accounts provide a group's orientation to reality and are not limited to dominant cultures. This is true also for the heterogeneous people known as American Indians, who were the first to populate the North American continent. - Dr. Henrietta Mann

“The sacred story of the Cheyenne creation is told only at night, the tradition formerly dictated that it be told solely by the spiritual keepers or medicine people of the tribe” (Mann,1997, p.1). According to oral tradition, The Cheyenne believe that “The Great One” has existed for eternity and created the universe. After he made humans from the sacred Red Earth Mother, he charged them with the guardianship of the four sacred persons that reside in a home at each of the four directions of the universe. The Creator charged The Cheyenne with traveling a “road of life,” which begins in the East where the sun rises. This road is individualized to each person’s unique journey of life, which also has its beginning in the East. This journey is a circular one and as a person grows and matures, it leads from the East to the South, from South to West, West to North, and final from the North back to the East where the circle is complete in the transformation from life to death and the sun rises upon a new existence. To The Cheyenne, life is a sacred circular journey from - and returning to - The Creator.

In their journeys, they came into contact with a prophet named Sweet Medicine. The Great One had sent Sweet Medicine to The People with four sacred arrows and a ceremony, the Arrow Renewal – a major ceremony where the life of the Cheyenne is strengthened and renewed. Their distinct identity as a tribe is rooted in the four arrows, the sacred gift from The Creator. Sweet Medicine also instituted a representative government, the Council of Forty-Four and a hierarchical structure in which the spiritual and medicine people of the tribe were granted the highest authority. In addition to governmental structure, he gave The People four major laws prohibiting lying, cheating, marrying relatives, and intertribal murder. He also directed them to adopt a value system consisting of love, respect, cooperation, generosity, understanding, humility, and maintenance of the Cheyenne way of life. “During the 446 years Sweet Medicine lived with the Cheyennes, they were happy and life was good” (Mann, 1997, p.2).

With the prophet’s journey nearing an end, Sweet Medicine directed The People to select a man of high moral character as Keeper of the Sacred Arrows. With this, Sweet Medicine gave his final prophecy, telling The People of the catastrophes they would encounter in the future. He spoke of misfortune, illness, disorientation and cultural loss that would haunt them upon their encounter and “association with a white-skinned people, who would come from the East bringing strange gifts, ways, and diseases” (Mann, 1997, p.2). He went on to prophesize that education would be the primary method the white people

would use to strip them of their cultural identity which will transform The People into useless and confused individuals. He assured the Cheyenne that if they kept and protected the Four Sacred Arrows and remembered his teachings, they would maintain their unique identity.

The teachings of Sweet Medicine and the story of creation, which are preserved today in ceremony, developed into the Cheyenne world view dominated by the sacred protectors and the number four. The symbolism is in the four cardinal directions (technically the four semi-cardinal directions) and the four sacred arrows. Life is entered in the East, and the road is travelled clockwise from the East to the South, then West and finally North. These symbols are “interwoven not only into the spiritual life of Cheyennes, but also into the mundane” (Mann, 1997, p.3). Today it is still important to enter from the East and travel clockwise as it is on the life road. The number four is sacred in Cheyenne culture – it is a number of completeness. Today, as in past history, the Cheyenne still travel the sacred life road.

1.3 The Spirituality of the Arapaho

“Arapahos still consider their genesis to be so sacrosanct that its mystique is closely guarded, and it is told only during the Flat Pipe Ceremony” (Mann, 1997, p.1). According to their oral history, the Creator created the Arapahos first and placed them in the center of the Earth. From what has been spoken of freely, Arapaho oral tradition tells of the prophet, the First Pipe Keeper, who floated on an endless body of water with the Flat Pipe, the duck, and the turtle. Fowler states that he prayed to the Creator, who told him to send the duck to dive and search beneath the surface of the water. The duck returned with dirt, which the Keeper placed upon the Flat Pipe. Then he sent the turtle to the bottom and he also returned with dirt. The First Pipe Keeper also put the turtle’s dirt on the Pipe. Then, in one motion, he blew the dirt off The Pipe in each of the four directions creating the Earth. He then proceeded to create the sun and moon, man and woman, and plant and animal life. He then created day and night and the four seasons. The First Pipe Keeper taught the First People – the Hinono’ei - the religious rites that they would need and placed the duck, turtle and Pipe into a bundle, and the Arapaho have been responsible for them ever since. “For the Arapahos the contents of the bundle are symbols of the creation and their custody of the bundle is a sacred trust” (Fowler, 2006, p.1).

The Arapahos believe that supernatural power, and the force of life itself, radiates from the Creator. During early times in Arapaho mythology, the Creator instilled supernatural power into other beings such as forces of nature (weather phenomena and natural processes), animals, and certain minerals. The Arapaho petition these supernatural beings for assistance and guidance. The Creator's power on Earth, however, is exhibited in the Flat Pipe. The sacred bundle from the creation story is an avenue through which people communicate with the Creator. In Arapaho tradition, elders play an essential role in "maintaining good relations with the Creator, and people sought their assistance in petitioning for supernatural aid" (Fowler, 2006, p.2).

Arapaho stories also include heroes, members of the tribe, who showed people how to prosper in the world. Through supernatural assistance, they made important discoveries or performed extraordinary deeds. These heroes and more are revered in Arapaho culture and they believe that supernatural forces assist their discoveries and inventions. "The Arapahos' major ceremonies were also believed to have originated in individuals' encounters with supernatural beings" (Fowler, 2006, p.3).

According to Fowler (2006), all Arapahos travel through four stages, or "hills of life": childhood, youth, adulthood, and old age. Males and females had different duties and responsibilities during each stage. "The Arapahos symbolically equated the life cycle with the movement of the sun, the four cardinal directions, and the progress of the seasons" (p.17). The Arapaho also believed in reincarnation and thought that a child born with wrinkles or with scars might be the reincarnation of an elder or someone who was wounded in a previous life.

1.4 Cheyenne Culture

In the late 1600s, the Cheyenne acquired horses brought northward from the Great Plains by the Comanche, Kiowa and other tribes. Horses forever altered culture for the Cheyenne. As Hoig (2006) states, "The men were often tall and lean and adapted so readily to mounted battle that they became some of the most feared warriors" (p.9). They became a formidable opponent in battle against other tribes that had defeated them prior to the arrival of horses. Previously held back by mobility in pursuit of the buffalo, horses provided the ability to succeed at the hunt. Buffalo meat provided food for both summer and winter, and hide that could be tanned into leather for ropes, clothing and a new kind of dwelling –

the tepee. They were seminomadic using tepees during the buffalo hunt as dwellings when away from the villages. “Because tepees were portable, they enabled Cheyenne warriors to take their families with them rather than leave them behind in unprotected villages” (Hoig, 2006, p.9). Although Cheyenne men became great warriors, the most revered members of the tribe were the chiefs. They were responsible for peace within the tribe and with other nations. At any one time, forty-four chiefs – four from each of the ten bands plus four principle chiefs – formed the council that governed the entire Cheyenne nation – the governing body handed down from Sweet Medicine.

“Although hunting, warring and lawmaking fell to the men of the tribe, much of what was essential to Cheyenne culture was the province of women” (Hoig, 2006, p.15), who ruled the all-important domestic arena. Women spent their energy and time on domestic tasks such as fixing meals, tanning hides and sewing clothing. When the camp moved, it was the women who rolled up the tepee and when they settled, rolled them back out again. If the settlement became permanent, women improved their tepees to make them comfortable homes with things such as raised mats and floors, benches, and cupboards. Prized by the entire band, the work that women performed became an important and revered contribution to the community. Although hunting buffalo was the source of the skins for the tepee and the province of men, the actual dwelling belonged to the woman or the woman’s family. It was her job to prepare the hides for use as a tepee covering, and the labor of the making of the home gave the woman ownership of the fruits of her labor (Paxson 2010). Another remarkable quality exhibited by Cheyenne women was their chastity. Often it took five years or more before a woman agreed to marry her suitor. The suitor did not approach her directly, but instead “he enlisted an aged relative – often a woman – who approached the girl’s family with gifts” (Hoig, 2006, p.16).

The Cheyenne culture included a formidable quantity of social tradition and ceremonies, some shared from other tribes that share a historic connection, and some that were unique to the Cheyenne. The Renewal of the Medicine Arrows as already mentioned was one such ceremony. Rituals also included several dances, the Sun Dance in particular. “It lasted eight days and was highlighted by a dance performed by young men whose chest were implanted with leather thongs tethered to a lodge pole” (Hoig, 2006, p.20). This type of self-torture tested a warrior’s tolerance for extreme pain.

Many of the Cheyenne religious and cultural beliefs influenced their relationship with white settlers. They developed the belief over time that white people were bad omens and did not trust the settlers. More concrete reasons would strengthen this mistrust as time progressed and the Cheyenne were destined for life on a reservation. This mistrust is still evident today in the difficulty that native students are facing in mainstream institutions. According to Gail Wilcox, admissions officer at CATC, at Southwestern Oklahoma State University (SWOSU), where the Cheyenne and Arapaho Tribal College is located, there are instances of both overt and subtle racism perpetrated by white students against native students. This makes the path to education even more difficult for the Cheyenne who wish to get a college education.

1.5 Arapaho Culture

It has been told by elders that long ago, Arapahos lived in Canada and moved to the plains where they eventually came in contact with the buffalo. They hunted this animal, as did the Cheyenne and many other plains tribes, on foot. This led them deeper into the plains where they obtained horses around the dawn of the 1600s.

The tribe was governed by chiefs and “divided into male and female age-graded societies, each spanning four years in a person’s life” (Mann, 1997, p.6). The number four was prominent in Arapaho society and helped form their world view. “The Arapaho had four lineages, four corners of the universe, four ancestral beings, four stages of life (childhood, youth, maturity, old age), spaced their children four years apart, held their lodge meetings for duration of four days, etc.” (Mann, 1997, p.6). The number four was integrated into every aspect of Arapaho life both secular and spiritual. It formed the base for the understanding of the universe, time and family. It represented the four seasons and the four directions so integral to their life on the plains.

An intensely spiritual people, the Arapahos participated in many important rituals and ceremonies, the most important of which was the Sun Dance. The Flat Pipe was given to them by the First Pipe Keeper and distinguished the Arapaho as the “chosen ones.” The Pipe symbolized peace and because of this emblem, “the Arapahos were divinely mandated to be a peaceable people” (Mann, 1997, p.6). Because of this mandate, they were taught by their elders to be respectful, patient and kind and to endure rather than fight. The Arapahos became known on the plains as traders, friendly and accommodating to all men and they

even contend that the word “Arapaho” means “trader.” This peaceful way about the Arapahos managed to keep them relatively free from violent confrontation with the white settlers, often taking a stance of endurance rather than resistance to their advancement. Today, tolerance is still a way of life as it is with the Cheyenne as they continue to face racism perpetrated mainstream culture.

1.6 Movement

The Cheyenne and Arapaho Indians are of Algonquian linguistic stock representing the western-most groups of the large Algonquian family that spread pre-colonially over the northern and eastern woodlands of the United States. Early migration history is only part of their oral culture and not considered important or critical to be shared with others, so the earliest acceptable mainstream written or physical evidence began around the year 1600. At that time the Arapaho were located east of the headwaters of the Mississippi River, bordering the western end of Lake Superior in current-day Minnesota. The Cheyenne were situated along the East bank of the Mississippi River in what is now Southeastern Minnesota. Each tribe lived in permanent, bark or earth-covered lodges. Their lives were a mix of hunting and farming, raising crops of corn, beans and squash. According to Hoig (2006), “the first contact between white settlers and the Cheyenne occurred in 1680 when a group of Indians visited the construction site of Fort Crevecoeur by the French explorer Rene-Robert Cavelier on the Illinois River. The Indians that visited “called themselves Tsis-tsis’-tas, or ‘The People” (p.8).

The first acknowledged migration in what was to become a relentless “moving about” took place around 1675, with both groups moving westward into the Dakota country. The Arapaho relocated along the headwaters of the Missouri River, while the Cheyenne settled in the same general area of North Dakota. Rather quickly, another move occurred during the early 1700s, further west, but south into the Black Hills of South Dakota. The Arapaho moved slightly ahead of the Cheyenne who, upon their arrival in the Black Hills, saw that they were already occupied by the Arapaho. “The Arapahos did not view the latecomers as intruders, but instead accepted them as friends, which resulted in a confederation of the two tribes” (Mann, 1997, p.5). As late as 1724, these uprooted farmers still used dog travois (sleds pulled behind an animal) to haul their goods. In 1804, Lewis and Clark reported some Cheyenne still residing in the Black Hills area. However, another migration was

imminent, taking the tribe south to the upper branches of the Platte River in Wyoming and Nebraska following the buffalo.

The first treaty signed by Cheyenne chiefs on behalf of the tribe took place at a gathering in Montana in 1825 on the Teton River. Around 1835, a portion of the tribe separated itself from the main body to become known as the Southern Cheyenne and Arapaho, settling along the Arkansas River in Colorado. It is this group that currently resides in several of the northwestern counties of Oklahoma.

The year of 1851 marked the final separation of the Southern Cheyenne from the main body, subsequently known as the Northern Cheyenne. As a result of the westward expansion of the whites, the Southern Cheyenne and Arapaho ceded all of their land claims in Nebraska, Kansas, Colorado, and Wyoming to the United States on February 18, 1861 at Fort Wise, Kansas. The United States in turn was to provide a reservation for them on a branch of the Arkansas River in Colorado. The Arapaho tribe was assigned to the eastern portion of the reservation, whereas the Cheyenne tribe was given the western portion. However, the agreement was never consummated.

During the fall of 1863, the whites became alarmed by inflammatory rumors of a general Indian uprising. The political feelings of Colorado settlers, combined with a highly anti-Indian attitude, prevailed and culminated in the famous attack by white settlers on the Cheyenne encampment under Chief Black Kettle. Many Cheyenne, mostly women and children, were killed during this event. The event is referred to as the Sand Creek Massacre.

Subsequent to the Sand Creek Massacre, the U.S. Government directed all Indians to report immediately to designated military posts. Part of the Arapaho and part of the Cheyenne responded and came to re-express their desire for peace. As a result, a commission was sent out in early 1865 to meet with them. An agreement was entered into and signed whereby the Cheyenne and Arapaho agreed to relinquish the reservation in southeastern Colorado, which they never occupied, and accept in its place a reservation further south in Kansas and Indian Territory. The agreement was formalized under the Medicine Lodge Treaty of October 28, 1867, establishing a reservation which was bounded on the north by the Kansas state line and on the east, south and west by the Arkansas and Cimarron River. After moving to this reservation, the described tract was found to be

unsuitable for their needs, and many were on the warpath again. "Then, by proclamation issued on August 10, 1869, President Grant approved the transfer of their original reservation to the present day western Oklahoma location" (Lesiak, 2007). The new reservation area was bounded on the east by the 98th degree of west longitude, north by a line contained in an 1886 treaty with the Creek nation, west by the 100th degree of west longitude, and south by the north line of the Kiowa-Comanche-Apache reservation that was established in the 1867 Treaty, and the Washita River. It was this latter area which the Cheyenne and Arapaho occupied as a reservation held in common from 1869 to 1890.

On November 27, 1868, Colonel Custer and his troops ruthlessly attacked one of the Cheyenne villages. Black Kettle was killed and his camp destroyed in one of the bloodiest massacres that occurred in Oklahoma, The Battle of the Washita. History refers to this event as a battle, however, the soldiers attacked the Cheyenne village at sunrise while they slept, leaving the Cheyenne unable to defend themselves. Bitterness engendered by this attack was a strong factor in Custer being defeated and most of the 7th Cavalry being killed by a number of different tribal groups camped along the Little Big Horn including the Cheyenne and Arapaho, as well as several Dakota (Sioux) groups.

In 1870, the first Cheyenne and Arapaho agency was established in Darlington, which is about two miles north of present-day El Reno, Oklahoma. It wasn't until 1875, five years after the first Cheyenne and Arapaho Agency was established that the Cheyenne retaliation came to an end from a military point of view. During all these troubled years, the Arapaho generally went out of their way to remain at peace in spite of their own great suffering.

The Jerome Agreement of 1890 approved by an Act of Congress on March 3, 1891 provided, in part, for the dissolution of the Reservation and the relinquishment by the Cheyenne and Arapahos of all the lands embraced within the boundaries of the reservation except for allotments to individuals and reserves for military, agency, school, school-farms, religious or other public uses. In 1890, as a result of the desire for more land by the white settlers, the Dawes Act was formalized whereby each Indian was to retain only 160 acres and the excess lands opened to white settlement. The Cheyenne and Arapaho country was opened for white settlers on April 19, 1892.

In 1937, the Cheyenne and Arapaho organized a government for their common welfare and adopted a Constitution and By-Laws pursuant to the Oklahoma Indian Welfare Act. Decisions and policies once made by chiefs were enacted in a representative committee of eight members elected for four year terms, on a staggered two year basis – a tribal government organization primarily driven by the U.S. federal government.

1.7 Education

In the latter part of the nineteenth century it was decided by the federal government, with the dedicated support of educators and other people of seemingly good will, that the only hope for Native Americans was to turn them into white men – to force them into the great modern mainstream of American life. By itself, this wasn't a new idea. However, making it official policy was new. Schools for the education of Indians were to be the answer. The announcement of one of them – the Haskell Institute in Kansas said, "Indian youth from 10 to 18 years of age were to be taught the elements of an English education and the simpler domestic industries and to prepare them to become intelligent industrious citizens" (Lesiak 2007). It sounds good in theory - a worthy program - and in some ways it was. Yet the true purpose of this new policy was a forced assimilation of Indians into the white man's version of society - to stamp out Native American culture – Indian religion, Indian law, legends and language - and in that light, it was often very cruel and short-sighted.

Formal education differed tremendously from tribal-specific learning and was a concept alien to the Cheyenne and Arapaho people. "Cheyennes could not begin to comprehend Sweet Medicine's predictions about the useless individuals white education would produce any more than they could anticipate the assimilationist goal of that type of education" (Mann, 1997, p.19). In 1778 the United States instituted the practice of making treaties with Indians which legally established the federal-Indian relationship.

In addition to treaty-making and military methods of extermination, the government instituted other policies to "civilize" the Indians. Special interests groups began pressuring for westward expansion and to pacify the pioneers, federal policy turned to relocating Indians to reservations. The Quakers were among those pressuring, but for different reasons. "They contended that Indians were human beings worthy of humane treatment and they should be provided with education and medical services" (Mann, 1997, p.22).

Brinton Darlington, an elderly Quaker, was appointed the agent of the Upper Arkansas Agency, Camp Supply, Indian Territory, arriving there on July 6, 1869” (Mann, 1997, p.23). Since the Cheyenne and Arapaho had continually refused to occupy the reservation that was created in the signing of the Medicine Lodge treaty, Darlington relocated the agency to the banks of the North Canadian River in 1870 near present-day El Reno, Oklahoma. The agency was named Darlington as a tribute to the agent. Henrietta Mann (1997) states that “the Arapahoes [sic] had developed a high regard for Agent Darlington primarily because he respected their traditional ceremonies and did not attempt to destroy them as most white people did” (p.24). Formal education was finally initiated among the Cheyenne and Arapaho under the Darlington Agency in 1871 when a day school opened on the reservation. Upon Darlington’s death, John D. Miles was transferred to Darlington on May 31, 1872 and assumed the duties as agent. Overwhelmed with the amount of work and lack of funds, Agent Miles appointed John Homer Seger to work with the Indians. John Seger was the first to work with the Cheyenne and Arapaho, remaining with them for over 50 years. “This kind white man, who treated the Indians as humans, was to have a tremendous impact upon their lives in the early stages of their transition” (Mann, 1997, p.27). He respected the traditions and culture of the Indians, even becoming intrigued with rituals and ceremonies. He headed the boarding school for the Cheyenne and Arapaho, however, despite being forced into the white man’s education, the Cheyenne and Arapaho managed to maintain their identities.

During a series of intense military battles in 1874 and 1875, known as the Red River War, the federal government exerted its strength by identifying Indian activists and offenders to be incarcerated and treated as prisoners of war. “Seventy-two Indians from five southern plains tribes (Cheyennes, Arapahoes [sic], Caddos, Kiowas and Comanches) were targeted for imprisonment at Fort Marion, the old Spanish fortress at St. Augustine, Florida” (Mann, 1997, p.40). Lieutenant Richard Pratt accompanied the prisoners to Florida and began an extensive three-year campaign to “civilize” the Indians. Their hair was cut. Their traditional clothing was replaced with military uniforms. The prisoners were instructed in English and were taught to be good soldiers – “good Indians.” The experiment caught the attention of many not only in the community of St. Augustine, but in Washington, D.C. as well. According to Robert Utley, “the Indian’s salvation lay in divesting him completely of all the trappings of his own culture and making him in every way except skin color another white Anglo-Saxon protestant, you know. I mean, a white ... Anglo-Saxon ... protestant” (Lesiak

2007). The experiment was considered a success. And thus, assimilation through education began in earnest.

Pratt wished to continue his work at civilizing the Indians, however, he emphasized that “the work of civilizing adult Indians was a slow process” (Mann, 1997, p.45). “In 1878 the commissioner of Indian affairs reported on the status of Indian education nationwide, stating that ‘Indian children are as bright and teachable as average white children of the same ages.’” Lieutenant Pratt, in 1879 stated “give me 300 young Indians and a school in one of our best communities and I will show you how to solve the Indian problem” (Lesiak 2007). Pratt knew that grown men can change only so much. To transform a people you must start with the children. This inaugurated the practice of sending students to off-reservation boarding schools located far from their families. The Carlisle Indian School was founded by Richard Henry Pratt in 1879 in Carlisle, Pennsylvania. “Carlisle placed an emphasis upon the English language, and its curriculum consisted of courses in reading, writing, spelling, arithmetic, and geography” (Mann, 1997, p.52). “Pratt set the agenda for the next 50 years of federally funded and controlled Indian schools” (Cornell, 2008, p.200). Pratt’s goal to “kill the Indian and save the man” became policy. “Indian schools sprang up across the nation. Over the next decade – 25 Indian schools opened in 15 states” (Lesiak 2007). In 1918 the Department of the Interior was notified that the Carlisle Barracks were needed by the War Department and after four decades, the Indian Industrial Training School at Carlisle, Pennsylvania, closed its doors on September 1, 1918. Any remaining students were transferred to schools closer to their reservations. “Most students went back to their homes on the reservations. There is no striking out, reaching for higher things when this happens. When they return to the reservation, they were neither white nor Indian but lived in the shadows” (Lesiak 2007).

As a result of the Indian Reorganization Act of 1934, the 1930s “finally saw a shift away from federal policies of forced cultural assimilation” (Cornell, 2008, p.200). Instead, allotment was ended and tribal governments were constitutionalized. “In education, the emphasis shifted away from off-reservation boarding schools and toward a willingness to recognize that native culture and community continuity could play positive roles in the education of Native youth” (Cornell, 2008, p.200). In reality, the education was simply less harsh in terms of assimilation and anti-indigenous culture attitudes. The Cheyenne and the

Arapaho schools, located on the reservation, were consolidated and renamed Concho School which remained open as a day school until the 1940s.

In 1934 both the Johnson-O'Malley Act and the Indian Reorganization Act were approved. Following those, in 1936, was The Oklahoma Indian Welfare Act which extended the option of organizing for tribal self-government to Oklahoma Indians. "The Cheyenne-Arapaho Tribes of Oklahoma ratified a constitution and bylaws on September 18, 1937, and organized under a white form of government" (Mann, 1997, p.182). The children had to be educated to cope with the changes, and were enrolled in public school in 1939.

Cheyenne and Arapaho education has been comprised of myriad of systems from church group schools, mission schools, boarding schools, federal schools and now public schools. "Historically, American culture has failed to respect Cheyennes and Arapahoes [sic] as a part of humanity; rather, The People have been perceived stereotypically as uncivilized museum relics. Consequently, Cheyenne and Arapaho education has existed solely to civilize, to assimilate, and to melt tribal members into the monolithic, impersonal white society. Despite government efforts, they have not been legislated out of existence" (Mann, 1997, p.184).

1.8 Government

In the early history of the Cheyenne and Arapaho Tribes, each Tribe was governed by a council of Chiefs. The Chiefs were selected from among members of a band to lead that particular band. The Cheyenne had ten bands, and the Arapaho had five. These bands were generally kin or extended families. The bands were represented at the council fires by an equal number of Chiefs. The Cheyenne Chiefs were chosen based on deeds and character, whereas the Arapaho chieftainship was hereditary. There were forty Cheyenne Chiefs – four per band – plus an additional four who were chosen to represent the Cheyenne Tribe as a whole. The Arapaho chiefs varied in numbers from ten to fifteen, with two or three chiefs per band.

After the reservation and allotment period, a de-facto authority was imposed on the Tribes by the U.S. federal military and the agents sent to look after the needs of the Indigenous people. Despite this change, the Tribes still looked to the Chiefs and elders of the Tribes for advice and counseling. According to Shirley and Solomon (1995), "the

damage from the Allotment Act extends well beyond land losses. The transfer of title in Indian lands within reservation boundaries to non-Indians, thereby enabling the establishment of large non-Indian populations on the reservation, has probably been the single most important factor in the erosion of tribal autonomy since the early nineteenth century” (p.3).

The Oklahoma Indian Welfare Act of 1936 (also known as the Thomas-Rogers Act) was an alternative to the 1934 Wheeler-Howard or Indian Reorganization Act. This Act defined specific provisions for all Indian tribes in Oklahoma to adopt a tribal constitution which allowed self-governance. The Act also made provisions to allow the Secretary of the Interior to purchase land to be held in trust for all Oklahoma Indians. The Act allowed small groups of Indians to form a local cooperative association and receive interest-free loans from the Revolving Loan Fund for Indians.

According to the Encyclopedia of Oklahoma History, the Act was developed in 1935 by Wilburn Cartwright, House Roads Committee; Representative-at-large William C. Rogers, House Indian Affairs Committee; and Elmer Thomas, Senate Indian Affairs Committee. It was agreed that the original Wheeler-Howard Bill applied to reservation Indians and did not relate to Oklahoma’s situation. Representative Rogers suggested that the original Act be rewritten in a manner which offered a more up-to-date new deal for Oklahoma Indians. The Thomas-Rogers Bill (Oklahoma Indian Welfare Act of 1936) was introduced by Senator Thomas on February 26, 1935, as S. 2047 and by Representative Rogers on February 27, 1935, as H.R. 6234. The original Thomas-Rogers Bill was rejected by Osage County, because a portion of the original bill called for the removal of probate control of Indian land, property, and money from Oklahoma courts and gave control to the Secretary of the Interior. A new bill was written with eight sections added, and Osage County was excluded from the Act. The revised Act provided provisions for the way individual Indians could obtain land and how tribes could adopt constitutions and obtain credit and lands, and issues regarding probate and inheritance were left to the state courts. The Oklahoma Indian Welfare Bill became law on June 26, 1936.

According to the Tribe’s website (www.c-a-tribes.org), the Cheyenne and Arapaho adopted a formal Constitution in 1937, upon passage of the Oklahoma Indian Welfare Act of 1936. The governing body was originally designated as having fourteen Cheyenne and

fourteen Arapaho members; however this was later amended to include seven Cheyenne and seven Arapaho designees, for a total of fourteen Business Committee members. This amendment was ratified on February 4, 1942.

According to the 2009 Base Report, a Constitutional revision in 1975 restructured the governing body of the Tribes to an eight member Business Committee with an equal representation of Cheyenne and Arapaho members. The new revised Constitution also established the Tribal Council, which consists of all tribal members over the age of eighteen. A quorum for the Tribal council required 75 members of that body for any general or special meetings. The constitutional revisions identified the several authorities for the Tribal Council including approval of the tribal budget, alteration of district boundaries, approval of attorney's contracts, and claims and recoveries of land to name a few.

On April 4, 2006, according to the tribe's website, the Cheyenne and Arapaho Tribes formally adopted a new Constitution and by-laws. The Constitution now requires a Tribal Legislature to enact an annual budget by law, which includes an appropriation of operating funds for the Tribal Council, the Executive Branch, and the Judicial Branch. The annual budget includes all revenue and funds controlled by the Tribes, which includes gaming revenue, and all revenue and funds received by the Tribes from all other sources. The Tribes operate on a fiscal year of January 1st to December 31st.

The Cheyenne and Arapaho Tribes are governed by an Executive Branch comprised of an elected Governor (currently Janice Prairie Chief Boswell, second governor of the Tribe), a Lieutenant Governor (currently Leslie Wandrie-Harjo) and a Chief of Staff (currently Ida Hoffman). The Executive Branch oversees, under the tribal administration the various commissions and departments (see Figure 1, Appendix A)

The Judicial Branch is comprised of one Supreme Court, one Trial Court, and other lower courts of special jurisdiction as deemed necessary by the Legislature, and other forums of special jurisdiction for traditional dispute resolution. The Supreme Court has one Chief Justice and four Associate Justices. The Trial Court has one Chief Judge, one Associate Judge, and other Associate Judges. The Judge and Justice for each court are selected upon nomination by the Governor of the Tribes, and are subject to confirmation by the Legislature, and final approval by the Tribal Council. The Chief Justice and Associate

Justice of the Supreme Court serve four-year staggered terms. All Judges and Justices of the Trial court serve four-year terms in office.

The Trial Court has original jurisdiction over all cases both criminal and civil. The Supreme Court has appellate jurisdiction over any case on appeal from the Trial Court. The Trial Court and the Supreme Court do not have jurisdiction over traditional religious matters, such as conduct of ceremonies or the possession of sacred objects. Each Court has specific powers and duties (see Figure 2, Appendix A). They have jurisdiction of Indigenous people, but in cases of homicide and non-tribal people, the U.S. federal law, through the FBI, has jurisdiction.

The Legislative Branch has the power to make laws and resolutions necessary for the benefit of the Cheyenne and Arapaho people. The Legislature shall enact annual budgets for all revenue and funds controlled by the Tribes. Cheyenne and Arapaho Legislative representatives are appointed by the Executive Branch and approved by the Legislative Branch to four Districts located within the tribal service area. The area is divided up into four districts for both the Cheyenne and Arapaho. District 1 consists of Seiling, Watonga, Longdale and Canton. District 2 encompasses El Reno, Calumet, Kingfisher, Geary and Greenfield. District 3 contains Thomas, Deer Creek, Weatherford, Colony and Clinton. Finally, District 4 surrounds the communities of Hammon and Elk City. Each District is further divided between the two Tribes, so that District 1 is designated as C-1 for the Cheyenne and A-1 for the Arapaho and so forth (see Figure 3, Appendix A)

1.9 Community

The Cheyenne and Arapaho people have two distinct histories and cultures. These cultures have been preserved for centuries and continue to be celebrated and embraced today by the tribal communities. According to the tribal website, the preservation of both Cheyenne and Arapaho cultures has become the focus of the tribal government as a whole. Today, a large percentage of the tribal population possesses both Cheyenne and Arapaho blood quantum. Because of this, the Tribes must begin to consider the associative standings or connections to both cultures, and determine the future impacts to both the Cheyenne and Arapaho.

With regard to historical context, the Cheyenne and Arapaho Tribes lived sedentary lives in their earliest history. They resided in villages of earth lodges located in the Great Lakes region of what is now Southeastern Canada. Later, they became known as Plains Indians, living a more nomadic existence in temporary villages of tepees. The two Tribes traveled together and often set up camps in proximity to one another for many years. They communicated consistently on matters affecting the safety and well-being of their members. The buffalo was the mainstay of their existence. Although these animals roamed in great herds, they were never killed for sport alone. "When a buffalo was slain, great care was taken to utilize the whole animal for varied purposes" (Hoig, 2006, p.16). The hide was used for clothing and bed coverings, the horns for ladles, the muscles for thread, and the meaty parts for food. Even the skull was preserved for ceremonial use. The fresh meat of the buffalo, not immediately consumed, was sliced and dried in the open air (Paxson 2010). Using this preservation method, the families had a store of meat that sustained them until the next buffalo kill.

An abrupt change in the nomadic lifestyle was forced upon the Cheyenne and Arapahos when the white civilization conquered the Indigenous populations in their push westward. Through various treaties, Executive Orders, and Agreements, the two Tribes were eventually stripped of all land claims save for 160-acre allotments. By this time, the white man had reduced the buffalo to near extinction as they competed with cattle for grazing area. According to the U.S. Department of Agriculture, buffalo carried Foot-and-Mouth Disease and Corridor Disease which does not directly affect the buffalo, but afflict cattle in reduction of weight, inability to produce milk, or even death in some cases. Therefore, buffalo were killed by the thousands by settlers wishing to graze cattle on the land. In addition, buffalo hides were one of the most indestructible materials for use as machine belts as part of supporting the industrial revolution. This contributed to the large scale slaughter and waste of the meat and other parts from the tribal point of view.

The Cheyenne and Arapaho were forced to change their free lifestyle of living off their vast lands, to a lifestyle of confinement to one area. Without their previous resources of sustenance, tribal members had to quickly adapt to a new way of acquiring food and clothing. "Almost immediately, the tribal members began selling off their lands for ready cash to purchase food and other essentials" (Base Report 2009).

According to the 2009 Base Report, the Cheyenne and Arapaho Tribal communities are characterized as mainly rural in population, development, and economic activity. Tribal communities are located in non-contiguous areas throughout a nine-county service area in northwestern Oklahoma. The Cheyenne and Arapaho tribal government has located community service facilities in four strategic locations within the historic reservation boundary. The community service facilities are located in Concho Reserve near El Reno, the Clinton Reserve in Clinton, the Canton Reserve in Canton, and in Watonga on the Franklin Reserve.

The tenacity to cling to what remains of the cultures and traditions of the two Tribes is noteworthy. The kindred societies still exist today, and the communities, not unlike the traditional encampments, have developed recognized leadership within themselves. Both the Cheyenne and Arapaho tribal members have established concentrated residences in specific areas within the historic reservation boundary.

In many tribal communities, the Cheyenne and Arapaho included, Pow-wows and giveaways are a means of redistributing the means of subsistence. Existing perceptions of pow-wows tend to focus on urban events that emphasize a multi-cultural mix of tribal representation, ceremonies and dances such as The Red Earth Native American Cultural Festival held every summer in Oklahoma City. However, most pow-wows and giveaways in rural Oklahoma are small town events that recognize a need within a social network for assistance. In Oklahoma, this “network facilitates a system of exchange and redistribution which is crucially important for Indian people, providing needy Native American families with the means of subsistence” (Moore, 1993, p.240). These subsistence needs include food, clothing, heating oil and health care. Moore argues that pow-wows and giveaways are a means to fill in gaps in a rural economy that is uncertain and to compensate for often erratic government social services.

The Cheyenne and Arapaho have one of most active pow-wow cultures in Oklahoma. Simple giveaways usually center on a “feed” where anyone that is able, brings a dish and chairs to the event. “The free food itself constitutes the most direct means of providing subsistence to needy people in the community” (Moore, 1993, p.245). After all are served, the needy again pass through the line to receive generous portions to eat, and surplus food to take with them. According to a conversation with Henrietta Mann, there

must be an abundance of food to save the hosts from embarrassment. According to Moore (1993), “in some communities there is so much food and so many feeds that it is possible for hungry families to subsist for some time just from the food distributed at giveaways, pow-wows and memorials” (p.245).

In places like Geary, Watonga and Clinton, there is at least one weekly dinner if not more. For Cheyenne and Arapaho culture, wealth is not embedded in what a family has or how much money they make but rather in how much they are able to give away and share with others. This is a throwback to the days along the Washita River where it did not matter how many ponies a family owned, but by how many the family could afford to give away. According to Moore (1993), “the most significant and most fundamental aspect of the giveaway and pow-wow complex is the redistributive function” (p.268). This fundamental aspect is based on the need to survive and keep people alive. In social terms, this redistribution is important because it “ties the formal aspect of the pow-wow, the ceremony, directly to the casual variable, the economy” (p.268). The concern for the community, to keep it together and strong is a core value of the Cheyenne and Arapaho tribes and is the basis for their survival as a people.

2 Relevant Theories and Literature

2.1 Ecological Sustainability

Sustainability has become a buzzword in the last decade, but its full meaning is complex, emerging from a range of different sectors. In practice, it has become the springboard for millions of individuals throughout the world who are forging the fastest and most profound social transformation of our time - the sustainability revolution. When the concept of sustainability emerges in conversation, the mind immediately goes to recycling, reusable canvas shopping bags, and hybrid automobiles. Unfortunately, none of these are truly sustainable.

There are few relevant definitions of sustainability that get to the heart of what environmentalists are trying to drive home. The idea of sustainability, when it comes to respecting the Earth, is related to the ability of a process or a cycle to go on indefinitely for eternity - which is beyond a human timescale and often beyond human comprehension. Current efforts of sustainability easily slide into definition 3 under the word "sustain." Efforts of conservation, recycling and driving hybrids are merely prolonging the inevitable. All humans are doing by these meager efforts is pushing back the date of inevitability – the day the Earth reaches a permanent and irreversible tipping point where its ability to go on as healthy as it is now will yield. The possibility that this has already happened is especially alarming considering how casually people are approaching the problem.

2.1.1 Greening Urgency

There is a difference of opinion on the urgency with respect for the need to go green and be sustainable. There are those that are of the opinion that small fixes over time will bring the problem of greenhouse gas emissions and global warming under control. Still others are proposing drastic and immediate changes urging that extreme action today is the only way to avert total catastrophe.

Auden Schendler (2009) has written a book entitled Getting Green Done. In his first chapter, entitled "Trench Warfare, Not Surgery," he paints a picture of calamity in the near future if something drastic isn't done today. He reports on the Intergovernmental Panel on Climate Change (IPCC)'s 2007 report which, after being created in 1988, has drastically changed its tone. Schendler states that we need to act now or we risk destroying life on

Earth as we know it (p.5). He also quotes the IPCC's leader, a scientist and economist named Rajendra Pachauri who stated that "if there's no action before 2012, that's too late. What we do in the next two to three years will determine our future. This is the defining moment" (p.5). He predicts that calamity will occur very soon if something monumental isn't done immediately.

Schendler is not alone in his demand for swift action. Others agree, although refraining from calling it "trench warfare," that the need to act is now and on a much larger scale with a faster pace than is currently being implemented. James Gustave Speth (2005) writes in his article Creating a Sustainable Future: Are We Running out of Time? that "we must conclude that we are at the early stages of the journey to sustainability. Meanwhile, the forward momentum of the drivers of environmental deterioration is great. "We are moving rapidly to a swift, pervasive, and appalling deterioration of our natural world" (Speth, 2005, p.19). His predictions are again for a faster than previously realized deterioration of the natural environment and the inability of the Earth to support human activity. He also states that humans are at the helm now of the direction of the environment and only humans can steer the planet away from destruction.

There is agreement in urgency as most authors are espousing the need for quick action. Alan AtKisson (2006) admits that incremental change has a small effect, but is not enough. He states that "dramatic and rapid change, in the form of extremely accelerated innovation is necessary to prevent continuing an ever increasing catastrophic damage to the Biosphere as well as adapt to those irreversible changes to which the planet is already committed, such as some amount of climatic instability" (p.234). He is also insistent that without extraordinary and dramatic change, the most probable outcome is convulsion and collapse. After this proclamation, he reassures the reader that "collapse refers not to a sudden or apocalyptic ending, but to a process of accelerating social, economic, and ecological decay over the course of a generation or two, punctuated by ever-worsening episodes of crisis" (AtKisson, 2006, p.234). In his article, he also expresses optimism that dramatic change and transformation is not so difficult to imagine and is possible on a human timescale.

2.1.2 Greening Locally versus Globally

The mantra “think globally, act locally” has been floating out in society for years. The idea is that if humans can perceive the global environmental crisis for how serious it has become and that action is needed, then making efforts to green one’s own life will contribute substantially to reducing the enormity of the problem. The sobering truth about this concept is that no one person can make any difference at all unless every single human on the planet puts forth conscious and relevant efforts to be green. The latter part of this realization is a utopic circumstance that cannot be realized. There are still many people who believe that global warming and climate change are not occurring. If they are, it is a natural cycle for the Earth. Therefore, there is a significant percentage of the population that will do nothing to curb their consumptive and environmentally damaging habits. A third group, between the believers and the naysayers, believe that it is happening and are concerned to a degree, and yet are still doing very little if anything to change their habits. This leaves a small percentage of the population who want action which means that any action a believer takes will have to be enormous to affect change on a global level.

Paul Selman (1996), author of Local Sustainability, believes that “the role of the locality is pivotal in moving towards an environmentally sustainable future” (p.3). He also proposes that international bodies and national governments must continue to be prime movers in reconciling economic and ecological objectives, but their statements will be pious and empty if they fail to convince and motivate individual citizens, households, businesses and organizations. He insists that “the key player in the transition to sustainability will be local government” (Selman, 1996, p.4). He is correct in stating that local governments work more closely with local people and can affect change better than a national government can – it all has to do with scale. The scale of the national government is overwhelming and is often perceived as callous to the needs of the individual. Local government, in contrast, is in “the backyard” of citizens and has the ability to affect changes that are important to the individual as this type of government represents the individual rather than the collective.

The public should be enabled and encouraged to actively work out long-term development and environmental visions for its living space. A model for such operation between planning authorities and the public is the Agenda 21 approach. As Marco Keiner (2006) writes in The Future of Sustainability, “individuals, associations and pressure groups

can voluntarily work out a consensus on the future use of human living space and its resources” (p.220). He also quotes several sources who wrote in the Regional Environmental Center that “public participation, different from the one existing in traditional representative democracies, must be present. Thus, a sustainable city requires institutions and systems that can facilitate public participation in decision-making regarding environmental use and management” (Keiner, 2006, p.220). Thus, motivating individuals to participate in local environmental awareness and solutions, if practiced on a broad scale across the globe, will facilitate greater amounts of change than if it comes from the central government. It is true that planning from self-help community organizations, non-profits, and grassroots initiative can become important as they contribute to problem-solving strategies on lower, basic levels. Authorities should support such organizations instead of arguing that they should follow ‘official’ policy” (Keiner, 2006, p.221).

At the same time as advocacy for local change begins to take hold, a call for another kind of local action is beginning to take shape. Native Americans have been pushed aside throughout history to make way for the principles of Manifest Destiny in which European settlers viewed North America as a vast supply of unending and exploitable resources. The principles of Manifest Destiny are the very cause of the environmental and resource crisis that exists today. Daniel Wildcat (2009) agrees and states that “we American Indians and Alaska Natives have been on the receiving end of Western ideas, opinions, and colonial institutions for five hundred years. Now we face a situation on the planet where Native voices must be heard in order to avert or hopefully minimize the deadly events emerging” (p.61). He reminds his readers that indigenous peoples of the North American continent had a connection to the land that respected rather than exploiting it. In terms of acting locally, Wildcat states that “indigenous peoples should establish their own carbon dioxide and pollution-reduction protocols. We need to compare notes and share stories with our relatives from the Four Directions and around the globe. Indigenous nations must exercise a sovereignty that throughout many traditions conceptualizes and expresses democracy as life-enhancing ecological practices” (Wildcat, 2009, p.63). In this statement, he is proposing local action that can become a model for the rest of the world and possibly spur action based on the connection that Native Americans have always had to Mother Earth.

Schendler (2009) argues from a different angle. He states that individual actions such as plans to buy a Prius and using a canvas bag at the supermarket are not enough.

He points out that the problem is just too big for local action to be effective unless those actions are significant. “We are talking about an enormous undertaking – it means hitting the reset button on society” (Schndler, 2009, p.20). He also states that in offices, measures like recycling are important, visible and necessary. However, if progress stops at the copy machine or the recycling bin, then it is ineffective. He states that “businesses (as well as consumers and governments) need to do some soul-searching to find their biggest lever, then use it” (Schendler, 2009, p.88). What he means here is not small individual action. He is proposing that each individual, company and government identify a monumental change that can be made to make a huge difference immediately. One thing that Schendler (2009) states, is that local action will “likely fail in their attempts unless complementary state and federal policies are put in place” (p.18).

2.1.3 The Greening of Energy

Currently there is something of an arms race to purchase renewable energy – or more properly stated – to purchase renewable energy certificates or RECs. An REC represents the environmental attributes of one megawatt-hour (roughly the amount of electricity it takes to run an average American home for a month) of renewable energy. The utility grid is a pool of both green power and brown (fossil-fuel-generated) power. Therefore, purchasing pure green power is impossible as what actually arrives from the pool is more muddy than green. Purchasing an REC means that the purchaser takes credit for that specific amount of green power within the grid. Some of the money from the purchase of an REC goes to the producer of the green power; the rest goes to the middle man at the power company. The more green energy from the wind, waves, solar and so-forth that are put into the grid system, the more RECs that are available for purchase and the less “muddy” the pool becomes.

Schendler (2009) points out this fact by stating that “if you want to buy green power – that is, renewable-generated electricity that comes from solar, wind, small hydro, biomass, or geothermal sources – you can’t plug in directly, to say, a wind farm, because the infrastructure for such a connection doesn’t exist” (p.152). He also states that the reason businesses purchase RECs is because it is a more a productive use of marketing dollars to receive good press rather than a purely environmental endeavor. He states that “the fundamental concept behind all RECs, proponents argue, is that their sale creates a market

mechanism to drive new wind development” (Schendler, 2009, p.166). Schendler does not believe this concept. He believes that “there is a looming problem” and he believes “there is corporate demand only for cheap RECs, which serve as a remarkable – and remarkably cheap – tool for brand positioning” (2009, p.167).

Alan AtKisson (2006) writes that in order to achieve sustainability, there is a need to “completely redesign and rebuild our energy systems so that they drastically reduce carbon dioxide and other greenhouse gas emissions” (p.241). The implications of this statement are staggering. The fact that every internal combustion engine, every coal-fired power plant, every methane-emitting landfill must be transformed or replaced with an alternative that is climate-neutral and environmentally benign is a daunting and expensive task. He continues to say that “we must speed up the innovation cycle and the depreciation cycle of capital investment” and need “breakthroughs in the spread of solar, wind, hydrogen, and other forms of energy, together with new policies to accelerate the transformation process” (AtKisson, 2006, p.241). This again is daunting, but not as severe as replacing all sources of power. It is often said that the technology is there, the research has been done, there’s just no interest in implementing these strategies because of the high capital cost of the transformation. It is time to get over this hurdle, as there are two choices: the rapid development of benign energy sources or environmental collapse.

There is one thing that these authors and many others are missing, however, and that is people can plug directly into sources of geothermal, wind, and solar power if it is being generated on-site. By focusing only on the grid, they are failing to acknowledge that such systems exist and that they are phenomenally successful in providing for most if not all of the energy needs for those who invest in the on-site model. For these applications, RECs are not even necessary and the individual, business, or institution that invests in this type of power generation can truly say they are sustainable. In the literature on sustainability there is a gaping hole created by the lack of research and information about on-site renewable power generation and the ability to run both off the grid and carbon-free.

2.1.4 Greening with Indigenous Knowledge

Daniel Wildcat (2009) is not only interested in local action, but in making an impression on the larger world about solutions to climate change and the need to progress quickly toward sustainability. He states that “the proposal to use indigenous knowledge to

save the Earth denotes knowledge as something not passively found in 'nature,' but something found in the experiential exploration of our human place within the natural world" (p.73). Indigenous knowledge is rooted in relationships and experiences rather than numbers. He states that "modern humankind too conveniently and mindlessly thinks of ecosystems and environments as 'nature,'" (Wildcat, 2009, p.76) rather than humans as a part of nature. The Western view is that humans are separate from nature - that they are two different things, and that humans should tame, control, or "steward" nature. As is increasingly obvious, nature is not as tame as it once was and is about to unleash an attack on humans that will put them quickly back in their place of subservient to, rather than dominant over, the environment. He is not suggesting that society revert to a pre-industrial lifestyle. Instead, he states that "indigenous knowledge reminds us that we can never literally go back – a linear pattern of thought par excellence – to the world we used to live in. However, even with dramatic climate changes, as indigenous traditions and lifeways have demonstrated and continue to demonstrate, we can move ourselves outside the boxes that enclose our physical selves and imprison our minds and spirits to find a world we can live in" (Wildcat, 2009, p.96). Indigenous knowledge and lifeways include circular and cyclical life activities and processes as in nature. Humans are currently living in a linear fashion that cannot be maintained in the long run, and possibly, not even now. Realizing that everything comes from the Earth and in time returns is just the wake-up call society needs to find a way to loop the linear back into a viable cycle.

2.1.5 The Greening of Architecture – LEED and the USBGC

According to the [Architecture 2030 Challenge](#) website, buildings consume more energy than any other sector. They cite that, according to the U.S. Energy Information Administration (EIA), the Building Sector consumes nearly half (49%) of all energy produced in the United States. Seventy-seven percent (77%) of all the electricity produced in the U.S. is used just to operate buildings. Globally, these percentages are even greater. With so much attention given to transportation emissions, many people are surprised to learn this fact. In truth, the building sector was responsible for nearly half (46.9%) of U.S. CO₂ emissions in 2009. By comparison, transportation accounted for 33.5% of CO₂ emissions and industry just 19.6%. It is true that the nation's economy depends on a healthy building sector which touches nearly every industry (from steel, insulation, and caulking to mechanical and electrical equipment, glass, wood, metals, tile, fabrics and paint) across all

sectors of the U.S. business economy (from architecture, planning, design, engineering, banking, and development to manufacturing, construction, wholesale, retail, and distribution).

Building green is en vogue – almost sexy – in the new millennium. There are several movements that have gained popularity in recent years to expose the virtues of building more energy-efficient and environmentally conscious buildings. However, there is a mixed review on the effectiveness of these programs. One such program was created by the United States Green Building Council (USGBC) called LEED – Leadership in Energy and Environmental Design. This is a rating system to certify green buildings based on a graduated scale from simply “certified” up to “platinum.” The program has spurred an architectural “green revolution” of sorts. For all of its advantages, LEED has some serious short-comings. In addition to LEED, another program spearheaded by Ed Mazria, an architect from Santa Fe, New Mexico; is the Architecture 2030 Challenge. The 2030 Challenge calls for all new construction, by the year 2030, to be carbon neutral with a gradual step-down in the years leading up to this goal.

Auden Schendler (2009) has a definite opinion about these programs, especially LEED. He states that “there is a strong case to be made that there is already a booming green building movement” and that the membership in the USGBC and LEED “is growing exponentially, from 250 members to 6,000 in a few years; recently membership has reached upward of 17,000” (p.174). Despite the new popularity of building green and all its benefits – better buildings, healthier, happier, more productive workers, energy savings, aesthetics – “green building has been agonizingly slow to take off.” One of the reasons for this, as Schendler points out, is that “the practice is often presented as a secret language, a form of Esperanto spoken only by William Shatner and a few weirdoes in the Haight-Ashbury” (Schendler, 2009, p.177). He suggests that knowledge of green building principles is like a foreign language or a secret handshake. In one breath, he thanks LEED because, as he says, “the idea – if not the practice – of green building has become understandable, even sexy, to the masses” (Schendler, 2009, p.177) due to the LEED certification program. In the same breath, he also criticizes LEED for failing to spur the movement toward more green buildings and gives three main reasons why. “First, it’s damn hard (costly, complicated, and tedious) to get certified ... second, LEED doesn’t emphasize energy enough ... and third, LEED is fundamentally a certification system but gets treated as a guide to green building”

(Schendler, 2009, p.180). LEED was always meant to be a guide and not a code. This flaw is readily understandable. The need for LEED certification exposes a flaw in the building industry as a whole – that building codes are not strict enough when it comes to energy performance, material use, and site considerations. Another issue is that “you can certify a building to a high LEED standard without all that much in the way of energy efficiency” (Schendler, 2009, p.182) which is a monumental flaw in the system. In fact, aluminum (which is a building material that is horrible on the environment in terms of energy intensity) can be used on the building in abundance if it is obtained within 500 miles of the construction site, which qualifies this material for a point towards green certification. The fact is LEED does not take embodied energy in materials and the most beneficial use of materials into account in its rating. Schendler (2009) points out that LEED is ineffective at measuring the true sustainability of a building project and “that’s why Ed Mazria started his own program, called Architecture 2030, to push for even more aggressive targets and eventually carbon neutrality” (p.185).

Jerry Yudelson (2008), author of The Green Building Revolution goes deeper than just LEED and the USGBC. He states that “the green building revolution is not just about the USGBC and the LEED process. It is a broader movement by the building industry to become more responsible: toward the occupants of its buildings; toward community infrastructure, energy and water, and other natural resources and materials; and toward the global environment” (p.6). He states that the green building revolution is important and has stated that changes in building design and construction could offset up to 6 billion tons of carbon emissions annually “through measures with a zero or negative net life-cycle cost” (Yudelson, 2008, p.1). He (Yudelson, 2008) is an advocate of green building and sees it as part of a paradigm shift toward sustainability, which is “a growing realization that current ways of living, made possible largely because of cheap and abundant fossil fuels, are not sustainable in the long term” (p.1). His book is purely about the green building revolution – its beginnings, current state of affairs, and future viability.

Stephen Roosa (2008), states in his book that “there was a time in the U.S. when most construction material was obtained locally. Indigenous materials included accessible timber, fieldstone, locally quarried rock, adobe, thatch, slate, clapboard, and cedar shakes. Since construction materials were costly to manufacture and troublesome to transport, most components of demolished structures were reused in some manner” (p.117). He goes on to classify a green building as one that contributes to minimal consumption of natural

resources, minimal atmospheric emissions, minimal discharge of harmful effluents, minimal impacts on the site, and maximum quality of indoor environment. Yudelson (2008) also offers a section in his book assessing LEED and its weaknesses. He notes that “interestingly, the unit of measure for evaluating energy consumption and performance in order to achieve credits is not a measure of energy (e.g., kilocalories or million BTUs) but dollars” (p.132). In effect, this suggests that architects and engineers adhere to inexpensive energy resources and then further reduce their use, rather than eliminating them completely. He also comments that the LEED certification process is too costly, too bureaucratic, fails to reward the best environmental solutions, and requires too much documentation. In his final comments, he says “the LEED process ... does not necessarily guarantee that in the end, the owner will have a ‘sustainable’ building” (Yudelson, 2008, p.137).

2.1.6 The Greening of Architecture – The 2030 Challenge

Ed Mazria, frustrated with rating systems, created the Architecture 2030 Challenge. He is proposing much more stringent reductions in energy consumption by the year 2030 than any other program. This challenge, which can be adopted by individuals, educational institutions, architecture firms, engineering firms and industries alike, is voluntary and does not push a political agenda for changes in building codes and performance requirements. The Challenge is broken down into two major categories for energy consumption: building materials and building operations.

The built environment is the major source of global demand for materials whose production results in the release of greenhouse gases. Planning decisions with regard to material selection not only affect building energy consumptions and greenhouse gas emissions, but transportation energy consumption and water use as well, both of which have large environmental implications. According to the website (Mazria, 2011), Architecture 2030 is asking the global architecture and planning community to adopt the following targets:

Immediately, products for new buildings, developments, and renovations shall be specified to meet a maximum carbon-equivalent footprint of 30% below the product category average.

The embodied carbon-equivalent footprint reduction shall be increased to:

35% or better in 2015

40% or better in 2020

45% or better in 2025

50% or better in 2030.

In addition to the embodied energy in materials, buildings are great consumers of energy related to operation and maintenance. Design and operation decisions greatly affect the efficiency of this consumption. According to their website (Mazria, 2011), The 2030 Challenge is recommending the following:

All new and renovated developments / neighborhoods / towns / cities / regions immediately adopt and implement a 60% reduction standard below the regional average for fossil-fuel operating energy consumption for new and renovated buildings and infrastructure and a 50% fossil-fuel reduction standard for the embodied energy consumption of materials.

The fossil-fuel reduction standard for all new buildings, major renovations, and embodied energy consumption of materials shall be increased to:

70% in 2015

80% in 2020

90% in 2025

Carbon-neutral in 2030 (using no fossil fuel GHG emitting energy to operate).

Mazria's Architecture 2030 Challenge is a drastic change in the way that buildings are designed, constructed and maintained. By doing all of these by the year 2030, Mazria proclaims that the carbon dioxide content of the atmosphere can be leveled at 2% of pre-industrial levels.

This we know: the planet will go on without us. But we cannot go on without it. At its core, sustainability is about people. In order to promote a healthy planet, we must start with a healthy society. This means taking action that is both environmentally sound and culturally sound. Action does not occur in isolation – it occurs when people become passionate and move toward change. In addition to being about science, sustainability is about society.

2.2 Cultural Sustainability

In this era of increasing homogeneity and globalization, local history, traditions, and ways of life are among the most endangered resources and precious assets. The desire to maintain local culture is strong in many communities and deserves some mention. Most people see sustainability as pertaining to the physical environment, and the need to preserve it for coming generations. However, sustainability can have as much to do with social science as biophysical science. While sustainability continues to be discussed in relation to development, planning, economics and the environment, in the last several years there has been an increased interest in exploring culture and sustainability from two distinct perspectives. The first of these perspectives can be framed as the role of culture in sustainability. The second of these perspectives can be framed as ensuring the sustainability of cultural practices.

Goucher College, the liberal arts college in Baltimore, Maryland is extending the concept of sustainability to “preserving the traditional values, as well as the arts, dress, customs and cuisines, of communities threatened by globalization and modernization, whether inner-city neighborhoods or third-world villages” (Goucher 2011). Goucher calls it cultural sustainability and offers a Master of Arts Degree in the subject. “Our program is about social justice and sustaining communities and in that way sustaining the environment,” says Deborah A. Cebula, the director of professional graduate programs and lifelong learning (Goucher 2011). Courses cover oral history documentation, cultural policy, management of events like festivals, use of exhibits and new media, advocacy, grant writing and fund-raising. Students work on projects in both rural and urban areas in the United States and overseas: in Kenya, collecting stories from children to help preserve native languages, for example; in Namibia, getting artists from disparate backgrounds to work together on programs.

The University of New Hampshire has established the Sustainability Academy to address cultural sustainability. “Sustainability certainly includes the air we breathe, the water we drink, the land on which we live, the food we eat, and all the connections between them that enable us to survive. But is that all you really want to do – just survive? Is that all you really want for your children and their children?” (UNH 2011). They challenge people to consider the word itself – sustainability – and ask what sustains. What makes life worth

living? What gives meaning and purpose and value to life? What is needed to not only survive but to thrive? “When you start to think about sustainability in this way, you start adding things to your list beyond just clean air and water. You start adding family, community, and democracy. You start including diversity, equity, and social justice. You list jobs and healthcare and education. And you even wax poetic and include love, beauty, art and music, history, and heritage” (UNH 2011). The UNH Sustainability program believes that at its core, sustainability is about humans that interact with and influence broader environments. “How can culture be separated from sustainability?” The need to consider how decisions are made about the collective future and the ethical and moral implications of those decisions is important.

"Sustainability is not about business as usual; it should not be confused with incremental technical approaches to managing the status quo more efficiently nor with the “greening” of consumerism. It is a question of culture: of our sense of meaning and purpose as Americans and as human beings. As citizens of the Earth system and citizens of the world, we have inherited a culture that is ours to interpret and bequeath to future generations. Sustainability requires us to critically examine our cultural choices in light of the myriad interactions of art, science, politics and economics, not simply to study them in isolation."

-Tom Kelly, UNH Chief Sustainability Officer

This is why UNH's Culture and Society Initiative (CAS) includes increasing community participation in and exposure to the fine and performing arts; increasing civic discourse among students, faculty, staff, and the local community on issues related to sustainability, cultural and natural heritage, public arts, justice, and sense of place; increasing common experiences that express a sense of place at UNH that can be shared by the entire community; and nurturing an historical consciousness through celebration of local and regional history. “UNH considers culture as fundamental to sustainability as clean air and water.”

Unfortunately there is little literature available about the subject of cultural sustainability. The main focus of anything connected with sustainability is that of ecological sustainability. In an increasingly global society, the need to preserve culture is becoming more of an issue so that the culture and identity of a place is recognizable in contrast to another. In effect, Daniel Wildcat’s book Red Alert: Saving the Planet with Indigenous

Knowledge, although mentioned ecological sustainability, is equally about cultural sustainability and sharing that with other cultures.

2.2.1 Sovereignty

The Indian Self-Determination and Education Assistance Act of 1975 (Public Law 93-638) authorized the Secretaries of the Interior and of Health, Education and Welfare to enter into contracts with, and make grants directly to federally recognized Native American Tribes. This authority gave the tribes greater control over the funding which affected their welfare. For instance, if a tribe needs a new health clinic, day care, etc., the tribe contracts with the appropriate government agency (called a 638 contract), then receives a grant and is responsible for building this infrastructure itself. Theoretically this process enables the tribe to manage their affairs more swiftly instead of waiting for a project to be managed by a federal agency and the red tape that accompanies it. In essence, this cuts out the middle-man who is often guilty of exerting control over the project to the detriment of the tribe.

Cornell and Kalt (2008) concur that for officially recognized American Indian Tribes, Alaska Natives and other Native communities in the United States, the contemporary era is all about self-determination as self-governing policies. "Native American affairs cannot be understood if Native peoples are seen as 'just another' ethnic minority. American Indian nations possess inherent rights as sovereigns that are recognized in hundreds of still extant treaties with the United States, in the Constitution, in court decisions, in congressional acts, and in executive orders that call for government-to-government relationships between the U.S. federal government and hundreds of federally recognized tribes" (p.371). They recognize the paramount importance of Native nations' status as sovereigns who have the ability to enforce laws affecting their respective communities' affairs.

There is much agreement in the literature about tribal sovereignty and self-determination. Kidwell and Velie (2005) state that "the sovereignty of American Indian tribes is a function of their original occupation of the United States (before it was the United States) as self-governing entities" (p.62). They recognize that tribal sovereignty is a basic concept for Native American Studies. They also state that "a corollary premise is that cultural integrity is integrally related to sovereignty. This is a political and social construct rather than a legal one. Cultural continuity is a requirement for federal recognition of tribes, but once a tribe is recognized, it is not compelled to demonstrate continuing culture.

Politically however, if American Indians cannot demonstrate their cultural distinctiveness within American society, Congress can simple terminate its government-to-government relationships with tribes and deny their sovereignty” (Kidwell, 2005, p.62). Therefore, if Indians look, act, talk, and live like all other Americans, congress cam simply cease to recognize sovereign rights. Therefore, there is a tension in the concept of sovereignty between the idea of federal responsibility for Native tribes as defined in treaties and the claim by tribes that they are not subject to federal power.

Warner and Tijerina (2009) add that “in the hierarchy of law, treaties supersede a federal statute. Treaties with Indian Nations are sanctioned specifically in the United States Constitution. Simply put, the treaties embody property rights over time. In exchange for land an Indian nation might receive among other benefits: health, water, hunting and fishing rights, housing, and education benefits” (p.111). They are quick to point out that there is a shift in the goals of Indian Nations from self-determination to self-actualization in current tribal agendas and subsequent law and policy initiatives have impacted this trend. These include “the Indian Child Welfare Act (1978), the Tribally Controlled Community College Act (1978), the Indian Religious Freedom Act (1978), the Indian Mineral Development Act (1982), the Tribal Tax Status Act (1982), the Native American Languages Act (1990), the Indian Arts and Crafts Act (1990), the Native American Grave Protection and Repatriation Act (1990), the Indian Tribal Justice Recognition Act (1991), and the Tribal Self-Governance Act (1994) – all designed to reinforce self-governance (Warner p.111). These acts are intended to protect self-determination however; mainstream philosophy did not always reflect these changes and Native Nations are often accused of accepting handouts and “welfare.” It is clear that many in mainstream society do not understand the fundamentals of trust responsibility.

Light and Rand (2005) acknowledge the legal definitions of sovereignty, yet point out that there is another angle to sovereignty that is often overlooked – the concept of cultural sovereignty. They state that “without a focus on internal priorities and values, sovereignty lacks a Native perspective and becomes only what the dominant society allows (p.20). Cultural sovereignty “encompasses the ability of tribes to define their own histories and identities, in part to counter stereotypes and imagery of the dominant society and is, as Coffey and Tsosie define it, ‘the effort of Indian nations and Indian people to exercise their own norms and values in structuring their collective futures” (Light, 2005, p.21). Cultural

sovereignty is the internally generated power to embrace and affect a Native people's cultural norms and values that assist in adopting or rejecting social and cultural innovations and to make progress as a nation that are culturally compatible with Native traditions and world views.

2.2.2 Tribal Economic Development

Much has been written about tribal economic development – what tribes should do, can do, and have done. There is not a clear answer on what type of development is right for each tribe, as cultures, values, governments, and geographic location varies drastically among Native Nations. One of the most visible types of economic development in the last few decades has centered on casino gambling. As Welch (2006) states, “in 1979, the Seminoles in Florida opened a bingo hall, with jackpots of \$10,000, in defiance of a state law prohibiting prizes exceeding \$100. “The success of that first small venture in bringing money, largely from non-Indian tourists, onto the reservation, encouraged other Indian nations to follow suit and open gambling establishments” (Welch, 2006, p.80). More than any other business activities, gambling operations have brought benefits to reservation economies. “A hefty portion of gambling revenues has been devoted to ensuring that traditional cultures are protected, not just as colorful relics from the past, but as viable societies that will continue in the future” (Welch, 2006 p.84). Light and Rand point out that “as one might expect, it seems plain from the results of much available research that tribes derive economic benefits from their casinos” however “the economic costs of Indian gaming to tribes mostly take the form of lessened economic benefits. For instance, the direct revenue transfers from tribal casinos to tribal governments are technically, in the eyes of some economists, a tax at a rate of up to 100 percent, theoretically bypassing private economic development” (Welch, 2006, p.92). This implies that there are fewer opportunities for a dollar to ripple throughout a tribal economy. But as tribes vary, so does the opinion of gambling operations. “Other nations reject casino operations as being contrary to traditional tribal teachings” (Welch, 2006, p.87). Light and Rand add to this saying that “for some tribes, gaming is simply not an option because their reservations are located in states that disallow any form of gambling. For others, isolated locales or lack of financial resources may restrict their ability to open or sustain a casino. Even in the absence of these practical limitations, a few tribes have chosen not to pursue gaming enterprises based on tribal values and beliefs” (p.9). Cordeiro (1992) also admits that “over the last decade or so, as

gaming has spread and non-Indians have flocked to reservations to play, some of these operations have had dramatic effects on Indian economies” (p.207). There is agreement in the available literature that gaming can be economically viable, yet culturally unacceptable.

Native Americans have a cultural basis for understanding the holistic nature of the Earth and human activity. It is no surprise that tribal development is veering toward natural resources. Smith (2000) points out that “one area of potential progress that most closely shows the possible compatibility between economic development and the other subsystems of Native American cultures lies in the environmental area” (p.77). Native Americans have long managed and cultivated natural resources successfully. They understand, more than most, the importance of human interaction with the environment and vice versa. “Traditional culture recognizes that renewable resources are to be managed with the understanding that short-term consumption should not occur at the cost of long-term sustained use. Resources are to be harvested but cared for in order to maintain the continued health of the ecosystem” (Smith, 2000, p.79). Native American culture often exhibits respect for the land and its careful use. Wildcat (2009) states that “nowhere are the anthropocentric features of the modern American worldview and modern notions of history more obvious than in our inattentiveness regarding water” (p.85). His book, in its entirety, suggests that Native knowledge can enter the environmental area and solve the problems facing the Earth and its systems.

As an aside to what tribal governments or tribal business committees can do to assist in economic development, there is also literature about individual and citizen entrepreneurship and economic development. Cornell, Jorgensen, Record and Timeche (2007) write that “often the development strategies guiding this (economic) activity focus heavily on businesses owned and operated by the nation. “The focus on tribal government as primary economic actor is understandable ... as Native nations typically confront urgent needs for expanded economic activity on their lands” (Cornell, 2007, p.197). They continue to suggest that another strategy is the independent business strategy that “refers to businesses started and owned not by Native nation governments but by their citizens – products of family or individual entrepreneurship, they operate independently of government but remain under the nation’s regulatory umbrella” (Cornell, 2007, p.198). The advantages cited to citizen-owned enterprises are numerous and include the generation of jobs, the building of community wealth, the building of a tax base, diversification of the tribal

economy; they retain local talent and broaden the development effort, support the tribal community, and strengthen tribal sovereignty. Smith (2000) also comments that “for reasons of culture and severe dependency, it has been argued that the concept of entrepreneurship is not pervasive in Native American societies” (p.129). He cites lack of capital as a major barrier to individual business ownership. Smith (2000) contends that “as education levels rise and the experience of the population increases, the likelihood of successful entrepreneurship increases. As individual tribal members gain expertise working in the tribal enterprises, they begin to dream of new and innovative businesses, which of course follows the development paradigm” (p.129). Smith’s approach is that by investing in tribal enterprises, the tribe will encourage its members to see the value of business ventures and then strike out on their own as entrepreneurs.

2.2.3 Tribal Colleges

Tribal Colleges and Universities (TCUs) are a rather new entrant on the scene of higher education. Beginning with the Navajo Nation in the 1960s, TCUs were slow to start, but have gained popularity and momentum in recent decades. This is due primarily to poor access to and retention in mainstream universities, and the desire to maintain tribal control of education. Currently there are 37 accredited Tribal Colleges and Universities in North America, with many more that have been established and are slowly building toward applying for accreditation with the American Indian Higher Education Consortium (AIHEC). Much of what has been written about Tribal Colleges has to do with the struggle to establish the institution, the difficulty in funding, poor student retention, and the contribution to the communities in which they operate.

Funding for Tribal Colleges is a hurdle that stays perpetually ahead of administrators and faculty. Wayne Stein (2009) writes that “in Title I of The Tribal College Act, \$6000 per American Indian FTE (full-time equivalent student) was authorized for Tribal College funding. Based on the Consumer Price Index, this authorization should now be approximately \$8,450 per student. “Either figure is significantly higher than the actual amount of \$4,447 per FTE appropriated in the 2005 federal budget” (p.25). At the same time, non-TCU community colleges were receiving \$7,000 per FTE from states and local non-Indian communities. “Tribal colleges do seek funding vigorously from a number of other sources such as federal agencies, philanthropic organizations such as the W.K. Kellogg

Foundation and the Bush Foundation, corporate foundations, and the establishment of their own foundation, the Tribal College Fund” (Stein, 2005, p.25). Unfortunately, TCUs must often compete with and lose out to non-TCUs for these funds. In addition, Douglas Clement (2009) refers to Tribal Colleges as “underfunded miracles.” Insufficient funding for higher education is a complaint that is common at all levels of higher education. “For tribal schools, the grievance seems particularly well founded. The Tribally Controlled College and University Assistance Act of 1978 mandates Congress to provide federal funding for tribal colleges, and the schools have relied on these allocations for core operational funding” (Clement, 2009, p.55). Tribal colleges, because they are generally located on reservation land, cannot depend on state and local taxes for additional funding. Due to inflation, federal funding, although increasing in monetary amounts, has actually decreased by 27%.

Tribal colleges were created because of the difficulty Indian students were having in mainstream colleges. Underprepared, culturally disoriented, far from family, Indian students in traditional colleges often dropped out before completing four-year degrees. Douglas Clement (2009) writes that “while retention has improved somewhat at conventional four-year colleges, the prevalence of dropping out motivated Indian educators to try a different path” (p.52). Frustration regarding retention is one of the reasons why tribal colleges were originated, while another was issues of culture and control. “Tribal colleges are close to home and provide culturally sensitive environments, factors that should improve graduation rates” (Clement, 2009, p.53). However, retention is still a challenge for many TCUs. Therefore, another approach called “stopping out” was created to assist single students who have children, students who have elders in need of care or experience a death, and other family responsibilities. “Stopping out is not a euphemism for dropping out, but rather a term to describe what many Indian students see as a necessary phase in attending college. The student may well return to college, but degree completion will often be substantially delayed while the student stops out to attend to other pressing concerns” (Clement, 2009, p.53). This provides flexibility for students who, by culture and tradition, have obligations in the home that take priority over educational goals. According to Williams and Pewewardy (2009), factors related to retention include academic preparedness, campus climate, commitment to educational goals, social and academic integration, and financial aid. One reason tribal colleges retain Native students more is because “there are American Indian staff serving these students and American Indian faculty instructing and teaching these courses who are from the respective tribe or local community who have personal ties with a

sincerity that is brought into the classroom” (Williams, 2009, p.151). This identity and connection provides more confidence in the institution and instruction. They also cite that programs that are relevant and specific to the needs of the local community and tribe also assist in retention as these programs have relevance to the students as being important knowledge and beneficial to them and their families. Carolee Dodge Francis (2009) comments that “as tribal colleges grow and expand both in infrastructure and student body, the praxis of paying particular attention to student needs (financial aid, family responsibilities, health issues, economic status, and prior educational learning) becomes crucial. Westernized college experience narration has emphasized the lack of attention to cultural understandings, thus perpetuating low American Indian student retention” (p.84). However, she also acknowledges that low student retention for TCUs is not exempt just because they are culturally responsive. She also points out that she believes that “the significant low retention and graduation percentages associated with American Indians attending Westernized universities and colleges have a direct correlation with the fact that we, as a People, are considered significantly insignificant” (Francis, 2009, p.85) As tribal colleges allow American Indian culture to thrive within the educational environment, Francis believes that TCUs can facilitate adaptability in their students for future success in other environments.

Tribal Colleges have the potential to positively impact the communities in which they are located. Preparing students for careers that fill specific needs within the community is the goal of most community colleges, and especially important for TCUs. Curriculum relevance is a key to retention, graduation, and later success within the community. As Stein (2009) points out, “TCUs, tribal governments, and local privately owned reservation-based businesses have done much work together to improve the economies of their reservations. Most TCUs have as a part of their overall mission statement, a phrase that states in some form that they will do what they can to promote the economic well-being of their community” (p.21). TCUs often conduct economic assessment studies to determine the needs of the immediate community and then design programs that revolve around those needs. “Areas of special concern to TCUs are those of curricula and programs that have been developed in response to tribal community needs” (Stein, 2009, p.29). “The positive impact of TCUs on the American Indian people and communities they serve is phenomenal, particularly as represented by the successes of their students in the workplace and in the mainstream institutions to which they transfer” (Stein, 2009, p.33). Clement (2009) also

points out that “tribal colleges have been looked to as economic engines, a means of generating improved living standards for individual Indians and their communities, in both the short and long term” (p.50). He backs this up with surveys that show better employment outcomes among tribal college graduates than non-graduates. Unfortunately, hard data on broad economic impacts of tribal colleges is scarce. However, Clement cites a 2000 report by AIHEC that concludes that “tribal colleges increase skill levels and foster employment in local economies” and that “tribal colleges are vital components of the process of building a foundation for future growth on Indian reservations and are strongly contributing to the economies of this nation’s most disadvantaged areas” (Clement, 2009, p.51). In addition to this, Clement (2009) points out that “tribal colleges located on reservations are often the largest local employer, with all that entails” (p.51).

Tribal Colleges are becoming important resources for the Native American Tribes they serve. Not only are they educating their students to become productive members of their own communities, but also catapulting them forward to even higher levels of learning in mainstream colleges and universities. In this way, TCUs are integral in preparing students for learning in a culturally rich environment so that if they do decide to pursue a bachelor’s degree, master’s degree or even a PhD, they are better prepared with academic performance so the transition to a different environment is less strenuous. Tribal Colleges instill confidence in their graduates – a confidence that is needed for cultural perseverance and are themselves economic development projects for their Nations.

3 Method of Design

3.1 The Cheyenne and Arapaho Tribal College

Oklahoma is home to 39 federally recognized American Indian Tribes. However, until this century, there were no tribal colleges in the state. During the past eight years, however, tribal colleges have been cropping up throughout the state, including the Comanche Nation College, the College of the Muscogee Nation, the Pawnee Nation College and most recently the Cheyenne and Arapaho Tribal College (Pember 2008). The Cheyenne and Arapaho Tribal College (CATC) is currently located on the campus of Southwestern Oklahoma State University (SWOSU) in the city of Weatherford, Oklahoma. Like the other tribal colleges in Oklahoma, CATC has formed an academic relationship with its sponsoring college to assist in conferring degrees as it pursues independent accreditation. As posed on the CATC website, SWOSU serves as a partner with CATC as it progresses through its initial developmental stages as a tribally-controlled institution of higher education. Once CATC becomes a fully operable and autonomous college, it will apply for Associate Membership with the American Indian Higher Education Consortium (AIHEC). The college opened to student enrollment in 2006 with fewer than 20 students and has since grown to an enrollment approaching 100 students in 2011. Until CATC receives independent accreditation and moves its administrative offices to an autonomous location, the Tribal College students are dually enrolled at SWOSU and subject to its admission and graduation rules and requirements.

According to their website, CATC personnel are working with various groups to develop associate's degrees and certificate programs. One initial program of study has been developed and approved by the Oklahoma State Regents for Higher Education, which will lead to an Associate of Science degree in Tribal Administration. This two-year A.S. degree was implemented in Spring Semester 2009 with some courses taught off-site through distance education. Students pursuing this degree, according to the college, will prepare themselves to work in the tribal environment, which is currently undergoing increased demands for individuals with administrative skills. In addition, three other degrees are offered by the CATC including two-year A.S. degrees in American Indian Studies, "gī ssh gon ni h hoo ssto'mo ssī ni vi 'ho'" (Children's Teachers), and General Studies which prepares students in general subjects to transfer to four-year colleges and universities. Detailed descriptions and requirements for the existing degrees are located in Appendix B.

The tiny college, which Cheyenne and Arapaho chief Lawrence Hart admits has a lot of “ifs” associated with its survival, has a definite edge (Pember 2008). That “edge” is its president, Dr. Henrietta Mann, of the Cheyenne tribe, who is well-known in Indian education circles. A native of Hammon, Oklahoma, Dr. Mann earned a Bachelor of Arts degree from Southwestern Oklahoma State University in 1954, and a Master of Arts Degree from Oklahoma State University in 1970. In 1982, she earned her Doctor of Philosophy Degree in American Studies from the University of New Mexico, Albuquerque. “She also holds the first endowed chair in Native American studies at Montana State University and is the author of Cheyenne and Arapaho Education 1871-1982” (Pember 2008). She has also taught at both the University of California, Berkeley and at Harvard University in Cambridge, MA. Dr. Mann began serving on the board of regents for CATC at its inception in 2003 before agreeing to serve as president when the college opened. According to Dr. Mann, the college will teach Cheyenne and Arapaho history through the voices of its people in the hope that this will help give Indian students a strong sense of who they are as they gain an understanding of their history and culture. “Our culture has sustained us for a long time. That’s why it’s so important for Indian people to know who they are,’ she says. ‘It’s been my self-appointed task to help ensure that American Indian young people learn these lessons” (Pember 2008). Dr. Mann has expressed the desire for the Tribal College to be a place of many cultures, embracing all who wish to obtain a higher education. Therefore, it should be an inviting and welcoming place for all who enter. This is evident in the CATC Logo which is a synthesis of the two tribes joint efforts (see Figure 4, Appendix A).

The emergence of tribal colleges reflects a growing movement towards self-determination and sovereignty by tribes says Carrie Billy, Navajo, deputy director of the American Indians in Higher Education Consortium (AIHEC) (Pember 2008). Tribes wish to deliver education to their members in traditional ways and immersed in culture while at the same time preparing students for jobs and careers in contemporary society. Dr. Mann agrees and points out that the tribal membership directed its leaders to create a tribal college (Pember 2008). Social problems in the community such as drug and alcohol abuse often go hand in hand with low self-esteem and lack of tribal pride and identity. In order to address this, the tribe began searching for ways to teach culture and language to their young people, instilling pride and confidence in their heritage. Thus, the genesis of the college was related to language preservation efforts by the tribe, reports Chief Lawrence Hart, a member of the Cheyenne and Arapaho tribes (Pember 2008). The college is a

symbol of the tribe's determination to preserve its culture and language as well as its commitment to instilling its younger members with a strong sense of pride and tribal identity.

At creation Tsistsistas and Hinónóéí (Cheyenne and Arapaho people) were given great minds with the ability to think and to learn. Consequently, they have always been visionaries and they made their decisions in terms of their impact upon the current and coming generations. One might characterize these cultures as being children-centered. Tsistsistas and Hinónóéí have always loved their children and have often said that they could see the future just by looking into their faces. They wanted and prayed for many good things for their children and grandchildren, including a good education. Simply stated they wanted their younger generations to be well educated because they believed in the power of the good mind. This was true in the past, and it is just as true today.

Education was their vision for you, just as it is our vision for you today. Tsistsistas and Hinónóéí linguistic and cultural ways are old and they extend far back to creation itself. Such ways are good for you today because they were good for our beloved ancestors. They also will be good for those who, too, will come to live on this beautiful land. CATC is a cultural sanctuary that promotes learning, as well as a place that honors the tribal identities of the Cheyenne and Arapaho. Remember that CATC is your tribal college. Explore your possibilities. Come to learn and understand. Develop the potential of your mind. Fulfill your dreams of an education. Vau- da-ma—Welcome! I honor you.

Sincerely,

Henrietta Mann, Ph.D.

3.2 Cultural Considerations in Design

Culture is an incredibly powerful tool in the design, creation, and significance of place. Architects do not merely design buildings, but instead they create a sense of location and security, a sense of being, and a sense of place. Architects that embrace culture and the significance of place become sculptors of the human experience. Architects that ignore culture become obsolete. The Cheyenne and Arapaho Tribes have an extensive history which has been thoroughly covered in Chapter 1. Their culture lives on and is strong despite two centuries of ordeals that threatened to assimilate them into the mainstream, forever erasing languages and beliefs that have existed through the millennia. The goal of the Cheyenne and Arapaho Tribal College is to “preserve culture through dignity and

respect.” It has to be the goal of the Tribe’s architecture to embody their culture and enduring spirit in a design to carry them proudly into the future.

3.2.1 Native American Architecture

Native architecture is a great example of sustainability without reliance on the western concept of mechanical technology. They survived extreme environments for centuries based on knowing what to build, where to build and how to build it. One of the goals of sustainability – even today - has nothing to do with technology. Instead it has to do with know-how and common sense. Using materials that can be found locally or right at the building site is one of the staples of sustainability often ignored when overshadowed by our seemingly relentless need for technical fixes. Westerners tend to be blinded by the shiny objects while they should be marveling at the simple and obvious choices in site and materials.

For centuries, humans have sought refuge from the outside environment within the strong arms of the Earth. “In the southwestern United States, Pueblo Indians built stone or clay chambers called kivas as early as 300 A.D for religious and ceremonial rites. The Pueblos also carved elaborate structures into high cliffs in Arizona, New Mexico and California, creating secure living spaces for themselves. These were arranged in a manner to capture winter solar angles and yet be protected during the summer months. The massive stone and clay structures held warmth for the winter and coolness for the summer” (Klodt, 1985, p.4). In the north, Alaska natives took advantage of the Earth’s protection by building permanent earth-bermed structures and temporary ice houses for hunting and fishing trips. An airlock entryway trapped cold air outside the main entrance of the dwelling.

One example of sustainable – not to mention beautiful – architecture is the cliff dwellings that belonged to the Ancient Puebloans of the Southwestern parts of North America. “Constructed with only the available materials of earth, stone and sunlight, these proto-urban settlements still appear strikingly harmonious with their high desert surroundings” (Nabokov, 1989, p.356). The reason that they mesh so well with their natural surroundings is that the Anasazi constructed them of materials found right on the site or very nearby. The structures appear to be carved out of the cliff, or appear as though they are extensions of the cliff or mesa under which they are built. One of the most famous of these cliff dwellings, Mesa Verde, is located in the Southwestern corner of present-day Colorado.

Using nature to their advantage, the Anasazi built their dwellings beneath the overhanging cliffs. Their basic construction material was sandstone that was abundant throughout the area. The sandstone was shaped into rectangular blocks similar to the size of a loaf of bread. The mortar between the blocks was a mix of mud and water. All local and available materials that made the cliff dwellings of Mesa Verde appear to be at one with their surroundings. In time, if left alone, the materials used to construct the cliff dwellings would return to the Earth and the site would appear untouched by human hands.

Another sustainable practice that is evident at Mesa Verde and especially at Cliff Palace is the use of the cliff's overhang to control the heat of the summer and winter sun. During the hot summer months, the sun was high enough in the sky (referred to as the sun angle) that the cliff face and overhang kept the dwellings in the shade for all or most of the day. This, along with the ability of stone to absorb heat kept the dwellings relatively cool. During the winter, the opposite is true. The lower sun angle during the winter months hit the village directly which assisted in keeping the area under the cliff relatively warm. The stone would absorb additional heat during the day that was slowly given off in the evening and during the overnight hours. This amazing yet simple use of passive solar energy seems to elude Western society even today as power-hungry air conditioning and fossil fuel furnace heat are used to battle nature's unbalanced hot and cold.

A third example of sustainable architecture can be found at Chaco Canyon in the Northwestern part of present-day New Mexico. Chaco Canyon's high-desert landscape - its long winters, short growing seasons, and marginal rainfall create an unlikely place for a major center of ancestral Pueblo culture to take root and flourish. In spite of a seemingly hostile environment, this valley was the center of a thriving culture. The monumental scale of its architecture created a cultural vision unlike any other seen before. Using on-site materials and masonry techniques unique for their time, they constructed massive stone buildings (Great Houses) of multiple stories containing hundreds of rooms. These structures were much larger than any they had previously built and were well-planned from the start. "Design was centralized and the role of the architect was at least rudimentarily present" (Nabokov, 1989, p.361). They were also oriented to solar, lunar, and cardinal directions to take advantage of sun angles, prevailing winds and rainfall patterns. The buildings were placed within a landscape surrounded by sacred mountains, mesas, and shrines that have deep spiritual meaning for their descendants. In addition, the mesas to the North provided

shelter from the biting winter winds while southern exposure to the winter sun caused heat to rise, which naturally heats the south facing roofs, walls and terraces. During the summer, the sun angle was high enough, the openings such as doorways were small enough, and the walls were thick enough to keep the interiors of the structure shaded and cool. The only material not indigenous to the area were the “massively timbered roof or ceiling of a typical room (which) required 40 beams, each a separate pine or fir tree obtained from forests up to 60 kilometers from the desert canyon” (Nabokov, 1989, p.361). However, since no fossil fuel was burned to bring those timbers to the construction site – only man power and animal power was used – it can be considered sustainable in terms of transportation and use of available materials.

Indigenous materials were one way the tribes of the Southwest were sustainable in their building practices. By using local materials, one can construct buildings that respect the area in which they are built and withstand the surrounding climate. Additionally, by using natural features or the Earth to shelter the built structures from unwanted wind and sun and orienting them in a way to take advantage of wanted sunshine during cooler seasons, the Native Americans of the Southwest were able to show even modern day designers the proper way to control the environment in the absence of technological fixes.

On the North American prairies, Indians and early European immigrants both took advantage of Earth sheltering to create earthlodges and sod houses. “Agricultural towns whose signature house type was the earthlodge were well established along the Missouri and Republican River systems” (Nabokov, 1989, p.124). They were built by tribes known as “village Indians,” who tilled the floodplains of the rivers and occupied these stockaded, Earth-sheltered villages in the hillside or on the plateau above. Earthlodges appeared around 700 A.D., housing the early farming cultures on the Plains (Nobokov, 1989, p.126). They were constructed by seminomadic villagers in the Plains. All of these people built the lodges in more or less the same fashion. Four or more poles were planted in the ground and joined at the top by cross beams. A wider ring of shorter posts and beams encircled this square frame. Radiating from the central smoke hole was a wheel of roof rafters that rested on the outer ring and to complete the frame, a slanting sidewall of covering posts was placed around the basic structure to hold the earth walls (Nobokov, 1989, p.126). The frame was then covered with a heavy layer of sod, woven grasses, or loose earth, often finished off with a final coat of wet earth which dried into a protective shell. These structures

provided essential protection against rain, wind, snow, and fire, and were easily constructed and repaired.

“The Cheyenne, who in the seventeenth century had been seasonal nomadic earthlodge farmers in the eastern Dakotas, rapidly abandoned their old life to become buffalo-hunting warriors” (Nabokov, 1989, p.158). By 1830 they had moved west and split into Northern and Southern Cheyenne groups who lived in tipis all year. “Scattered hunting and warring bands of Cheyenne gathered as an entire nation for councils, Sun Dances, and other ceremonies. The Cheyenne, like most Plains tribes, arranged their tipis into highly organized and well-policed camps” (Nobokov, 1989, p.159). The tipis were arranged in C-shaped rings with the opening facing east. Such a camp might contain up to 1000 tipis in a ring 3 or 4 dwellings deep (Nobokov, 1989 p.159). Tepees have transformational qualities that keep them sustainable and comfortable across the seasons. During summer months, the sides of the tepee can be rolled up allowing breezes to enter, forcing warmer interior air to exhaust through the smoke hole at the top. During the winter, additional layers are added to the interior with air spaces between to provide insulation. In addition, pine branches and blankets are placed on the floor as additional insulation.

3.2.2 The Land

In addition to Earth-integrated dwellings, Native American culture had a great respect for the Earth and the land. Whereas in Western culture, land is considered a commodity or a supply of resources to be exploited, Native Americans respect and protect the land. As Caleen Sisk-Franco (Wintu) states, “When you look at the land, what is the first thing people see? How they can make money on it. So it’s money, or learning how to value what looks like nothing. Because when the people came here, they said, look at the Indians, they’ve done nothing with this land. Well in our world view it’s like, that’s great. It looks so natural, that’s the way it’s supposed to be” (McLeod 2002). Native American spirituality recognizes that some locations in the landscape seem to have unusual power. Religion, therefore, is greatly connected to the land and place. Author Vine Deloria Jr. (Lakota) says that “it’s not like we designated the place and said this is going to be sacred, it came out of a lot of experience. The idea is not to pretend to own it, or not to exploit it, but to respect it. Trying to get people to see that’s a dimension of religion is really difficult” (McLeod 2002). In the proposed design for the Cheyenne and Arapaho Tribal College, the academic building is

placed down into the land which allows the Earth to assume the role of protector and provider. As Henrietta Mann stated, “the Earth shelters us and provides for our well-being.” In this case, the Earth will shelter the building while literally and symbolically protecting its inhabitants.

3.2.3 The Culture

How does one go about creating something that is culturally authentic? Is it even possible and if it is, who will be the judge as to whether something is indeed authentic? What is authentic? Carol Krinsky (1996) points out that “a problem in certifying that something is authentically Native American is that there are no universally recognized spokesmen, even within one tribe, and no single American Indian opinion” (p.40). Encompassed within what is currently the United States, there are over 300 recognized Native American tribes as well as many others that are “authentically” Native American, yet not recognized as such by the Federal Government. Not being recognized, however, does not negate their authenticity. If there is tradition, culture, religion and customs that are inherited from the past, then there is cultural authenticity – authenticity that cannot be denied even in the absence formal recognition. The authentic doesn’t just have to do with the past; however, it has to do with what “is.” Cultures and traditions change over time and evolve into what is known and felt at the moment. What is traditional or authentic isn’t one moment frozen in time, but instead it is what is arrived at based on where one has been. As Jean-Marie Tjibaou eloquently stated, “what is traditional? It is how others lived before us. But in one hundred years it will be how we are living today that is traditional, and in one thousand years, what we are living today will perhaps be worth its weight in gold! I believe we have an overly archeological conception of culture; the culture of the past is considered authentic, but that which is of contemporary creation must be proven authentic, perhaps by time” (Findlay, 2005, p.65).

With regard to the Cheyenne and Arapaho, there are many things both spiritually and culturally to take into account when designing for the combined tribes. Any designer will see that it is impossible to incorporate all aspects of these two cultures into a single building project. Therefore, those aspects that are common to both cultures should be incorporated, and those that are decidedly different should be omitted. As a consequence, both cultures will take pride and ownership in the building because the aspects that are present are

readily identifiable as part of their heritage. Therefore, the Tribal College design can fall under the second and third principle that Krinsky (1996) states are important in design: “it is collectively interpreted (that is, common meanings are attributed to its forms); and that it is collectively consumed” (p.41). Thus, the design should be interpreted as both authentically Cheyenne and Arapaho, and be utilized or “consumed” by both groups because they feel it speaks to everyone.

The Cheyenne and Arapaho people have two distinct histories and cultures. These cultures have been preserved for centuries and continue to be celebrated and embraced today by the tribal communities. According to the tribal website, the preservation of both Cheyenne and Arapaho cultures has become the focus of the tribal government as a whole. Today, a large percentage of the tribal population possesses both Cheyenne and Arapaho ancestry. Because of this, the Tribes must begin to consider the associative standings or connections to both cultures, and determine the future impacts to both the Cheyenne and Arapaho. Therefore, in designing the Tribal College, two cultures have to be explored to arrive at a synthesis that will feel as comfortable to the Cheyenne as it will to the Arapaho.

From the first meeting with the Cheyenne and Arapaho Tribe about the design of the college campus, many desires came to light. However, design goes beyond square-footage, office space, classroom space, and the like. Instead, it is the statements that have a deep connection to culture that are important and imply a greater meaning for the site than any numbers could describe.

“These are the things I took notes on. I took notes on comments I heard – seemingly unimportant things, yet these notes drove my design” (Riley Christopher, Author, 2009).

“Mother Earth sustains us.”

“Rocks are the oldest part of Earth.”

“In Oklahoma the Earth is the color of our skin, and the color of our skin is the Earth.”

“We believe that God has put the Earth, the plants, and the animals here for our use.”

“We must use the Earth responsibly and return all that we have used back to the Earth.”

“The College should be a place of many cultures.”

“These are the notes that drove my passion for designing and my desire to create a place of life, learning and culture that the Cheyenne and Arapaho would be drawn to – that anybody would be drawn to” (Author, 2009).

Often people look at contemporary designs for Native American communities and question how 'Indian' the buildings are (Krinsky, 1996, p.41). The time is not 1545 or 1790 or even 1945. It is currently 2011 and even though a designer should take tradition and history into account when designing a project for a Native American community, replication of a dwelling or building type that has long since passed is not necessarily a method that should be employed to make a building more "authentically Indian." The Cheyenne and Arapaho no longer live in earthlodges, teepees or even on a reservation. They live in contemporary Oklahoma on allotment land that is scattered and interwoven with western society. Renzo Piano wrestled with this dilemma when he was working on the Tjibaou Cultural Centre in New Caledonia. One problem is that "while the Kanak (New Caledonia's indigenous people) had no monumental or permanent buildings, they did have a technique of building passed on through the generations" (Findlay, 2005, p.54). The goal was not to replicate these structures, but instead to acknowledge and incorporate them in the overall design – something that can be identified by the Kanak as a traditional technique or experiential quality. Replication was not the key – the technique or experiential quality was the focus and should be in a contemporary building project. As Findlay (2005) points out, "at this point in time, the Kanak culture has already been irretrievably altered – it exists right now only in an internationalized condition. It would be patronizing to expect these people to return to their pre-colonial era way of life or technology" (p.64). This also holds true for Native American populations. Their way of life has been so drastically altered, that going back to historic forms of architecture would actually be foreign to them. Instead, culture has to be woven into contemporary ideas in order to be viable as a design and to convey the authenticity of the population as they move forward.

3.2.4 The Significance of the Cheyenne Life Road

To both the Cheyenne and Arapaho, the four semi-cardinal directions and the four stages of life are paramount in their culture and beliefs. Therefore, the use of the Cheyenne Life Road (see Figure 5, Appendix A) played an integral part in the design of the campus – especially the academic building. The southern quadrant of the life road, contained between the southeast and southwest cardinal direction lines, is the time of life in which learning takes place. As children begin to mature, they enter the age range of 12 to 28 in which learning takes a more specialized focus. This age range is the time in which students make choices about their direction in life with regard to career and family goals. They have grown

from being a small seedling with strong cultural roots into a supple willow tree shaped by traditional teachings. It is the time to learn, be flexible and physically strong – yet still in need of direction from elders and teachers. It is a time to understand where they stand in the greater world. The southern quadrant symbolizes the summer growing season and is represented by the element of wind.

With this in mind, the academic building was designed to fit, in its entirety, in the southern quadrant with its submerged walls pressed firmly on the southeastern and southwestern cardinal direction lines (see Figure 6, Appendix A). The entirety of the southern learning quadrant is contained within the embrace of the Tribal College academic structure – symbol and a cue for students to embrace the academic and cultural teachings of their elders.

The east is the time of youth, of early childhood development and learning and encompasses young ones from birth to age 11. Taking this into account, the proposed Early Childhood Development Program and Daycare is located in the east wing of the academic building. Not only does this nod to cultural symbolism, but places this program nearest to the east entrance to the property and allows for a separate entrance for parents bringing children. This is also where the administrative offices are located. Just as the east is the symbolic entry and exit from this world, so too is the administration a symbolic entrance to and exit from the academic experience from admission to graduation.

The west is the time of adulthood from age 28 to retirement. It is the time where a person is strong like the cottonwood tree, steeped in traditional knowledge. It is the time “to do.” During the life phase, adults often start a family, maintain their culture, and take care of children. It is the time to protect. With this in mind, the proposed Nursing Program facility is located in the west wing of the academic building also symbolizing taking care of others and protecting families, including the whole tribal family. It is also the time to protect oneself and stay active and healthy. Therefore, the Wellness Center will also be located in the west wing as a nod to protection – in this case protection of one’s own health.

The space between the wings encompasses an outdoor plaza that can be used for festivals, concerts, or just spending time outdoors. The handling of the land between the wings needed to be as subtle and gentle as the curving glass of the building façade. Therefore, the landscape slowly ascends from the plaza back up to grade level creating a

beautiful natural amphitheater capable of accommodating hundreds of people as spectators for anything that may be occurring on the plaza. With the curving expanses of glass, the open-air plaza, and the gently ascending landscape that returns to the surface, it is impossible to believe that the building is actually integrated into the Earth as views of the sun, the sky and the land are accessible from within the structure itself.

As soon as the shape of the building began to materialize, it was apparent that locating the building in the southern quadrant had other advantages. The main advantage is the ability to have the southern sun, during the winter months, passively heat at least a portion of the building. Passive solar systems rely on expanses of south-facing glass to capture the sun's heat for storage within the building. In addition, being Earth-integrated on the north, northwest and northeast side will protect the building from prevailing and cold winter winds. Finally, the grand stairway that ascends from the outdoor plaza to the original grade level on the north side of the building creates a natural auditorium space beneath it, allowing for the installation of a large theater space without additional effort and without any wasted space.

With all of these key elements brought together, the Cheyenne Life Road created the design for the Tribal College and the layout of the rest of the campus around the academic building. The only thing left was to sculpt it into an authentically cultural space that will inspire teaching, learning, culture, respect, and the human spirit.

3.3 Sustainability Considerations in Design

Given the high levels of energy consumption in the United States as well as the developed world in general, generating this power uses considerable un-renewable resources. These resources are being used at a rate that is 1 million times faster than these resources were originally formed. "The world consumes an average 12 billion kilowatts of energy per year, which is rapidly increasing. However, this amount is dwarfed by the flow of energy that the Earth receives from the sun, which is more than 7000 times larger and averages 87,000 billion kilowatts" (Musgrove, 2010, p.6). The incoming direct solar radiation, however, is rather low in comparison and averages 1000 watts per square meter of surface in bright sunlight (roughly 93 watts per square foot). The solar energy hitting the Earth can be harnessed both directly and indirectly for use by humans. Direct uses include passive solar heating, solar water heating, solar collectors (for electric production), and

passive air flow to name a few. Indirect uses include the capture of energy from wind, the tides, and the hydrologic cycle.

The Cheyenne and Arapaho Tribe envisions a college campus that is sensitive to the environment and produces a very light footprint on the resources of the planet. The discussion began with the desire to install wind turbines on the site. In addition, they were in favor of being “off-the-grid” where the college campus has the ability to function without inputs from local utilities. This desire to be independent fits into the concept of sovereignty and autonomy where they do not have to rely on established methods of providing energy and water services.

Detailed analysis and research on the proposed systems for the Cheyenne and Arapaho Tribal College is beyond the scope of this thesis. However, brief mention of each system is essential to understand the reasons for selecting specific materials for the construction of the project. Following the descriptions is a section that will tie the intended systems to the materials that contribute to their successful installation and operation.

3.3.1 Wind Power

The dual threats of climate change caused by burning fossil fuels and increasing fossil fuel prices make the development of alternative energy sources more urgent than ever. The high standard of living that developed countries enjoy is supported by massive consumption of oil, gas and coal – the fossil fuels. Carbon dioxide emissions caused by the combustion of these fuels is changing the global climate, and those that deny it is occurring and it is the direct result of human activity are turning a blind eye to the obvious. “Electricity generation is the largest single source of carbon dioxide emissions, and the need to move to the production of electricity in ways that avoid these emissions has stimulated a surge of interest in renewable sources of energy” (Musgrove, 2010, p.xiii). With this, energy provided by the power in the wind is likely to gain popularity and presence. Wind power has the potential to make a substantial contribution to meeting electricity needs in the United States. “A wind turbine is a machine which converts the power in the wind into electricity- which is in contrast to a windmill which is a machine that converts the wind’s power into mechanical power” (Manwell, 2002, p.2).

Wind power use has been on the increase since the early 1990s in Europe, the United States and elsewhere, and the global installed wind power has been “doubling every three to four years. The global installed wind power capacity increased from just under 2000 megawatts at the end of 1990 to 94,000 megawatts by the end of 2007” (Musgrove, 2010, p.22). It is now making the transition from being a minor contributor to becoming a major player in the generation of power.

Average wind speeds vary significantly from place to place but at on-land locations with good wind exposure, such as those that are chosen for wind farms, the average wind speed at the hub height of a modern wind turbine is typically in the range of 7 to 8 m/s (15.6 to 18 mph) which corresponds to an average power density of about 500 watts per square meter. The average wind speed in the Weatherford, Oklahoma area ranges from 16 to 18 mph, which is considered good for wind power generation. In addition, there is a major wind farm located nearby which confirms the viability of turbine installation on the Tribal College site.

When it comes to wind energy, size, especially rotor diameter, matters. “Today’s wind turbines range in size from the minuscule Marlec 500 with a rotor or only .5 meter (1.7 feet) in diameter to giant machines whose rotors reach nearly 100 meters (330 feet) in diameter” (Gipe, 2004, p.8). The small machine is capable of generating up to 20 watts in a stiff wind while the large machines are capable of 3 megawatts or 3,000,000 watts. A medium-size wind turbine can range from 500 kilowatts (5000 watts) up to 1.5 megawatts (1,500,000 watts). The blades of a modern wind turbine efficiently intercept the air flowing through the whole area swept by the blades, even though the blades occupy only about four or five percent of this area. Power densities relative to the blade area are therefore typically in the range of 10 to 20 kilo Watts per square meter, and these relatively high power densities, coupled with the engineering process made in wind turbine technology over the past 30 years, lead to energy payback periods of just a few months. In other words “all the energy used in a wind turbine’s construction, installation, operation and eventual decommissioning is repaid by its energy output during its first few months of operation” (Musgrove, 2010, p.8). “The annual operation and maintenance costs for wind turbines generally range from 1.5 to 3% of the original turbine cost” (Manwell, 2002 p.431). The size and number of medium-size turbines is up to the Tribe, as it will take only one 1.5 megawatt wind turbine to effectively supply electricity to the college campus. Any additional

generating capacity can be an economic boon to offsetting the capital costs of the turbines and perhaps the construction of the College itself. A good deal of energy, up to 70%, is lost in transmission and thus collecting or generating it on-site creates a compact campus design and reduces the amount of lost or wasted energy.

The question is often raised: will a wind machine pay for itself? A realistic answer to this question is another question: does it need to pay for itself? “Eric Eggleston, a wind energy engineer, notes that for those living off the grid it’s a question of the least costly way of getting electricity to the site” (Gipe, 2004, p.71). Electric utility companies will run power lines out to almost anyone that agrees to pay for its installation. Large commercial-size turbines intended to produce bulk power in competition with conventional fuels are cost-effective. However, smaller turbines need not pay for themselves overnight and as long as they prove beneficial, they will pay for themselves within their expected lifetimes. They generate electricity cleanly and without detrimental effects on the ability of the environment to function. That has value – a value that’s not currently incorporated in the price of utility-supplied power – meaning that environmental degradation costs are not part of a consumer’s electric bill. “The traditional way to assess the value of wind energy is to equate it to the direct savings that would result due to the use of the wind rather than the most likely alternative – referred to as avoided costs” (Manwell, 2002, p.443). However, the incorporation of environmental benefits far outweighs the mere dollar savings of the avoided costs. Often, the installation of a wind turbine not only pays for itself, but can actually make its owner money as it will most definitely produce more energy than is immediately needed, opening the possibility of supplying power to the grid.

Wind power is often criticized because the output from wind farms is variable, and on occasion will be small or even zero during periods of high demand on calm days. Wind, it is then said, is unreliable and it would be a waste of money and resources to build thousands of megawatts of wind power capacity. What such statements fail to recognize is the very important difference between energy and power. The problem is how to meet future energy needs that is reliable, affordable, and with substantially reduced greenhouse gas emissions. “Though the power provided by the winds does indeed vary substantially from one day to the next the winds are – year by year – a very reliable source of energy” (Musgrove, 2010, p.219). Wind power’s greenhouse gas emissions are non-existent, and wind turbine technology has progressed to the point where the energy payback period is short.

Wind turbines typically generate electricity for “about 75% to 85% of the hours in a year and all the time they are operating they reduce the amount of electricity that has to be generated by fossil-fuel power stations” (Musgrove, 2010, p.220). In the case of the Tribal College, an excess of electricity will be produced and will therefore be input and sold to the grid. In addition, when weather conditions change, the lights will not quickly “go out” as some fear. The air over a single region weighs many billions of tons, and when it is moving it cannot suddenly stop. Weather systems in fact take many hours to cross a region and the overall output from wind farms changes relatively slowly, which gives ample time to begin drawing from the grid.

One significant environmental issue which emerged in the Altamont Pass Wind Farm outside of Palm Springs, California was that “a larger than expected number of birds had been killed by collision with the wind turbines or their power lines, and these included raptors such as the golden eagle” (Musgrove, 2010, p.119). “All human-built structures contribute to bird death - there’s no benefit in sugar-coating that fact” (Gipe, 2004, p.298). However, the accusation that wind turbines produce more dead birds than electricity is false. “In fact, nearly 100 million birds per year are killed in the United States in collisions with the glass facades of buildings” (Musgrove, 2010, p.119). Studies were conducted in Altamont Pass in 1982 that found 182 dead birds, of which two-thirds of which were raptors. Later studies of other wind farms in California determined that Altamont Pass is unusual in that it has a high raptor population, plus many thousands of wind turbines in a relatively small area. Painting stripes on blades and adding noise-makers have been tried, but have produced little results. “Subsequent experience both in the United States and in Europe has shown that there is minimal risk to birds from the operation of properly sited wind turbines” (Musgrove, 2010 p.120 and Gipe, 2004 p.301). The main recommendation is to conduct a survey of a proposed wind farm site to assess the impact that wind turbines would have on all species in the affected area.

Noise is another misinformed complaint from those that oppose wind power. Despite technological progress, no operating wind turbine is or will ever be silent. Wind turbines are audible to people nearby. Whether it is noisy or not is subjective and far more difficult to determine. Since noise is measurable, it warrants some clarification. “The sounds they produce – the swish of the blades through the air, the whir of the gears inside the transmission, and the hum of the generator – are typically foreign to the rural setting where

wind turbines are most often used” (Gipe, 2004, p.285). Generally, wind turbines are quiet and although they produce a distinct sound foreign to any landscape, they are normally as quiet as the breezes in the trees. What is quiet? To Mick Sagrillo, a wind turbine’s quiet “when you have to go outside to see if it’s running” (Gipe, 2004, p.293).

Safety can be an issue with wind turbines in ways that many may not realize. “In the public safety arena, the primary considerations associated with wind energy systems are related to the movement of the rotor and the presence of industrial equipment in areas that are potentially accessible to the public” (Manwell, 2002, p.505). Some of the hazards associated with wind turbines include blade throw, falling ice or thrown ice, tower failure, worker hazard, and electromagnetic fields. Regular maintenance will assure that the blades are secured properly, the tower is designed and operating properly, and that workers use safety harnesses when climbing tower ladders. The electromagnetic field is usually generated around power lines and electric generators. “The magnetic field is created in the space around the conductor, and its field intensity decreases rapidly with distance” (Manwell, 2002, p.506). The final problem, ice, is an issue during winter months and can be a problem if Oklahoma experiences one of their famous ice storms. “As the blades warm, the ice melts and either falls to the ground or can be thrown from the rotating blade” (Manwell, 2002, p.505). Falling ice and snow from the nacelle and tower is a danger to anyone standing at the base of the tower. It is safest to both locate the turbines a safe distance from dense populations on the site and to cease operation of the turbines during heavy snow or icing conditions.

Another issue regarding wind power compared to other power sources is that wind generation systems or wind farms are often considered to be land intrusive, rather than land intensive. The actual footprint of each wind turbine’s tower is minimal. What most people are referring to is the visual impacts. Simply put – the aesthetic qualities of a wind farm are subjective and are in the eye of the beholder.

The two main reasons to install wind turbines on a site have been discussed: to reduce dependence on fossil-fuel-generated energy and to reduce the cost of energy for individuals and companies. Weatherford, Oklahoma is the home of the second largest wind farm in the state proving that it is a suitable location for wind power generation. The turbines for the Cheyenne and Arapaho Tribal College will do just that. However, they will

also assist in teaching students how wind energy works and that it can be a valuable part of the community.

3.3.2 Passive and Hybrid Solar Heating

The various strategies for designing a building that utilizes solar energy can be broken down into three categories: passive solar, hybrid solar and active solar. In terms of passive solar heating, as well as facts about solar energy, little has changed in the past several decades. "In general, active systems employ hardware and mechanical equipment to collect and transport heat" (Mazria, 1979, p.28). Collectors mounted on the building, along with a separate storage unit make up the major elements of the system. Photovoltaic solar panels, one type of active system, operate at only 9 to 12% efficiency. This means that of all the solar radiation that strikes a PV panel or array, only a maximum of 12% is converted into usable energy. This, coupled with the fact that PV panels are still very expensive, make them a costly capital investment with minimum impact.

Passive systems, on the other hand, "collect and transport heat by non-mechanical means" (Mazria, 1979, p.28). This is a system in which thermal energy flows by natural means such as radiation, conduction and natural convection. In essence, the building or structure is the system. For passive means, direct gain and hybrid systems are the most efficient and cost-effective methods of collecting and using solar energy. Using passive solar allows not only for heating, but also daylight, cooling and an open and airy building. There are three components that make up a passive solar system. The first is the collector and unlike active solar systems, it is not attached to but incorporated into the building in the form of unobstructed south-facing glass. The second component is the storage which is also referred to as the mass. The third component is convective loops which are warm air currents that form inside the structure as a result of the heating of air just inside the glass and move through the space.

The first and simplest approach to passive solar heating is the concept of direct gain. "Simply defined, the actual living space is directly heated by sunlight" (Mazria, 1979, p.29). When the actual space to be heated is used as a solar collector, it must also contain a method for absorbing and storing enough daytime heat to maintain comfortable night temperatures. "Direct gain is primarily a heating-type system, used mainly in mild and moderate climates" (Crosbie, 1998, p.13). The distribution of heat is generally not as crucial

to the operation of the system because the heat is stored in the same space in which it is used. The conceptual simplicity of this system is compelling. "As a result of intelligent planning and minor modifications in standard building practice, the building itself becomes the passive solar system" (Crosbie, 1998, p.33). One important concept to note is that a direct gain system is always working. This means it "collects and uses every bit of energy that passes through the glazing – direct or diffuse" (Mazria, 1979, p.29). Because of this, direct gain works well in both sunny climates and cloudy climates where great amounts of diffuse solar energy can still be utilized; where active systems can hardly perform.

The collector in all passive solar buildings is made of specific expanses of south-facing glass. "South-facing glass (the collector) is exposed to the maximum amount of solar energy in the winter and minimum amount in the summer" (Mazria, 1979, p.29). "The solar collector component is composed of transparent glazing, sealed in a frame and located on the south-facing side of the home (or building)" (Crosbie, 1998, p.12). This can consist of vertically-positioned windows or sloped at an angle. In the 1960s and 1970s it was common practice to orient collection glass at a 70-degree angle to the ground which is the optimal angle for maximum solar gain. There are two major problems with this concept. First, this peculiar angle made many passive solar buildings look odd to people. Aesthetically, humans have become accustomed to living in buildings with 90-degree angles and vertical glazing. Second, glass is a brittle material that has a difficult time supporting its own weight, unless placed vertically. To place a wall of glass on a 70-degree angle, the panes would have to be thicker to support its own weight and resist hail damage, and must be made of multiple smaller panes for the same reason. The more framing that is involved, the more obstructed the glass becomes and the less effective it is. At a 90-degree angle, it can be expected that its efficiency will decrease less than 1% making vertical installation of the south glass preferable. A passive solar system works because of the "greenhouse effect." As sunlight (short-wave infra-red radiation) passes through glass, it is converted into long-wave infra-red radiation which is heat. The glass will not permit the long-wave radiation to escape and thus creates a one-way flow of radiant energy.

"A good rule of thumb, for maximum efficiency, is 2 square feet of south glass for every 10 square feet of building floor space" (Block, 2011). The south-facing glass, to be an effective solar collector, needs to have a clear and unobstructed "solar window." This "window" refers to both a time of day and a clear angle to the sun. "Roughly between the

hours of 9:00am and 3:00pm during the winter months, the glass should be in full sunlight. From the base of the center of the glass, it should be clear from 19 to 30 degrees above the horizon at 9:00am and 3:00pm. Between these times, at noon, the glass should have unobstructed access to the sun from 25 to 48 degrees above the horizon” (Block, 2011). The only obstructions that are tolerable are deciduous trees. First, they provide magnificent shading for the south glass during the summer months. Secondly, they drop their leaves in the fall allowing sunlight to come through at approximately 90% as trunks and branches do cause a 10% decrease in the amount of sunlight striking the glass. The solution in this case is to increase the amount of south glass by the percentage of loss.

Mass is the second major component of a passive solar building. The storage component is composed of material that has the capacity to retain heat for a period of hours or days. “The slow rate of heat discharge from the storage materials helps maintain a steady, comfortable temperature within the spaces to be heated” (Crosbie, 1998, p.12). In most cases, the mass can also be used to keep a space cool by absorbing excess heat from the surrounding air. In general, mass consists of concrete, brick, stone, water or phase-change materials.

Of these, concrete is the easiest to place in the building as it is used regularly as a building material and can be poured and placed precisely where it is needed. Brick and stone are also suitable materials, but have their drawbacks in being more difficult to construct. Water is one of the most efficient in storing heat. However, convincing a client to fill a wall with water is difficult due to the fears of leakage and water damage. “Potentially the most efficient heating system is a eutectic salt chamber” (Block, 2011). The salt being used is sodium sulfate deca-hydrate ($\text{NaSO}_4 \cdot \text{H}_2\text{O}$ -- Glauber's salt). Glauber's salt has the convenient property of melting at 90 degrees Fahrenheit and stores about 83 calories per gram. Thermal storage using water is not nearly as efficient, as water only stores one calorie per gram per degree Centigrade. It does not take a large volume of salt to heat several rooms. The salt in the chamber is stored in black tubes or cans to pull in the day-time sun so that the salt melts. At night as the salt freezes at 90 degrees Fahrenheit, the air is heated around the tubes like a radiator.

In any case, the storage material (mass) must be exposed to effectively absorb and release heat. In addition to being exposed, “the mass must be sized according to the

amount of solar heat the collector is intended to provide” (Crosbie, 1998, p.12). A good rule of thumb is to provide 150 pounds of mass per square foot of south glass (collector) as a minimum for the system to function. A better number, one that assists in storing enough heat for a 48-hour period, is 225 pounds of mass per square foot of south glass. Thermal mass offers two important advantages. “ Mass stores heat when there is an excess of passive solar energy or internal gains in a building and releases the stored heat as the building starts to cool down” (Hastings, 1994, p.49).

The third component of a passive solar system is convective loops. Solar radiation entering the glass causes the air that is immediately inside to heat. This air then rises toward the ceiling. As more warm air follows, the loop begins. The heated air moves along the ceiling, then down the back wall and across the floor. If both the back wall and floor are exposed mass, the air will lose its heat to the mass as it returns to the window. This is also true if the mass is only located in the floor. As the cooled air returns to the glass, it heats again. This is a continuous cycle as long as there is solar radiation being transmitted through the glass. If the mass and the air reach equilibrium during the day, which happens between 78 and 80 degrees Fahrenheit, the mass is full and it is good practice to dump excess heat by opening windows close to the ceiling. At night, the process reverses. As the air film inside the glass cools, the mass releases heat and the loop will reverse up the back wall and across the ceiling toward the cool glass. As it loses heat to the glass, the air will fall and move across the floor where it picks up more released heat. This loop is continuous until the temperature of the mass and the air have equalized.

In a hybrid system there is the addition of a small fan which moves the warm air from the convective loops to where the mass is located. This fan can be auxiliary, or part of the mechanical heating and cooling system. For the Cheyenne and Arapaho Tribal College, fans will be necessary to move convective loop heat from the glass into the mass.

Convective loops will work naturally up to a point. The rules of thumb for effective loops are a maximum of two stories and a 30-foot depth from the glass. Instead of relying on natural loops, the Tribal College is constructed with hollow-core concrete slabs for the second and third floors. A fan attached to the back of these slabs will draw the warmed air from the convective loops into the cores in the slabs where it will be absorbed. When the sun is no longer producing radiation through the glass, the fan will be turned off and the core slabs will be permitted to radiate the heat back into the space.

“Of all the solar types, direct gain passive is the easiest to envision and construct” (Crosbie, 1998, p.13). “In fact, even during a harsh winter, the solar gains through south windows can exceed the heat losses out of the windows if the design of the building is optimized for direct gain” (Hastings, 1994, p.47). Direct gain passive solar requires all rooms to have south-facing glass, therefore internal rooms are “detached” and cannot be directly heated. One of the earliest and largest contemporary examples of a direct gain system is St. George’s County Secondary School in Wallasey, England. The building was designed by Emslie A. Morgan and was completed in 1962. “Public reaction to the building at the time was that the architect had somehow harnessed a new physical principle” (Mazria, 1979, p.31). The building was constructed of masonry with a transparent glass south wall for maximum solar gain in the winter. Concrete forms the roof and floors while the north wall and interior partitions are constructed of 9-inch brick. In contrast, the entire south wall of the building is transparent. “Two sheets of glass, the outside layer clear and the inside translucent, made up the roughly 230 by 27 foot wall” (Mazria, 1979 p.31). The south wall admits enough solar energy to supply about 50% of the building’s heating needs during the year. Wallasey is located on the west coast of England. Although the Gulf Stream moderates the outdoor temperatures, the current also brings in a substantial amount of fog and clouds. “In a climate, at best thought to be marginally suited for solar energy application, the building is heated 50% by the sun with the remaining 50% supplied by lights and students” (Mazria, 1979, p.31). The installed mechanical heating system was never used. This illustrates the power of solar radiation in the heating of buildings even in less-than-ideal environments.

“Buildings that are shaped without regard for the sun’s impact require large amounts of energy to heat and cool” (Mazria, 1979, p.79). When designing a passive solar building, it is necessary to think about admitting sunlight into the building. “A building elongated along the east-west axis will expose more surface area to the south during the winter for the collection of solar radiation” (Mazria, 1979, p.79). This is also the most efficient shape, in all climates, for minimizing heating requirement in the winter and cooling loads in the summer. Elongating the building in the east-west direction exposes the southern façade to solar radiation that is desired in the winter, and minimizes the façade especially in the west when summer heat gains are unwanted from that direction. “In all northern latitudes (32 to 56 degrees), the south side of the building receives nearly 3 times as much solar radiation in the winter than the east and west sides of the building” (Mazria, 1979, p.82).

The north side of a building is generally the coldest and darkest. This is generally the least-used side because it receives no direct sunlight during winter months. "From September 20 to March 20 (6 months) the north wall of a building and its adjoining outdoor spaces are in continual shade" (Mazria, 1979, p.86). During these months the sun is low in the southern sky. In addition, prevailing winter winds generally come out of the northwest, north or northeast which makes this side of the structure an energy-loser. During winter months, winds from the southwest, south and southeast generally cause a warming of temperatures and are more desirable. Shape the building so that the north side slopes toward the ground and contains fewer windows or places where the building can lose heat. "When possible building into the side of a south-facing slope or berm earth against the north face of a building to minimize the amount of exposed north wall" (Mazria, 1979, p.86).

Placing the building on the site for maximum solar gain is crucial. However, there is flexibility when orienting the south glass. If the glazing (collector) faces due south, this maximizes the solar exposure. However, loss of character or design by maximizing solar gain is the opposite of good design. A "tipping" of the building where the south-facing glass is within 5 degrees of due south will not cause any loss in solar gain. A tipping between 5 and 15% will cause a maximum loss of 3% of the solar gain intended. More than a 15-degree tilt will cause increasing significant losses in the collector's effectiveness.

"The opportunity to utilize a passive system for summer cooling is often overlooked since the major emphasis of passive building design is on keeping warm in the winter" (Mazria, 1979, p.262). There are two effective elements that cause a passive system to work: south-facing glass for heat gain and thermal loss for heat storage. These elements, when properly designed, have the potential to provide both heating and cooling benefits. For cooling, the south-facing glazing should be protected from summer sun angles to reduce or eliminate the direct gain of solar radiation. "In addition to protecting the glazing from the sun, it is essential that the windows in the building are operable and allow for natural ventilation. Open the building up at night to ventilate and cool interior thermal mass" (Mazria, 1979, p.262). Then plan for large openings of roughly equal size so that inlets face the prevailing nighttime summer breezes and outlets are located on the leeward side of the buildings opposite the inlets. Another way to accomplish this is to have the inlets vent on the lowest floor and the outlets at the highest point in the building to take advantage of the "stack effect" where hot air rises, and is replaced by cooler air down low, and naturally vents

itself out. Then, “close the building up during the daytime to keep the heat out” (Mazria, 1979, p.262). Closing up the building during the hottest time of the day may seem counterproductive, but this keeps the warmer air from entering the building while the thermal mass absorbs excess interior heat. If necessary, a small amount of conditioned air can be added to the spaces in extreme heat waves and is best performed with a geothermal system. This air conditioning will also assist in the removal of humidity from the air, which is essential in humid climates. These processes are referred to as “night-purging” and are used to release the stored heat in the mass and to prepare the building to absorb excess daytime heat. This requires, and ties in to the need for natural ventilation to facilitate needed air-changes within the building and to assist in maintaining thermal comfort. “Passive solar design techniques require utilization of natural ventilation to transfer heat from hot zones to cool zones in winter and for natural cooling during the summer” (Athienitis, 2002, p.2). In addition, ground cooling and heating to transfer heat to and from the ground or water body, which are more or less at constant temperature, are also very effective in passive solar buildings.

There are several other types of thermal storage including thermal storage walls (Trombe walls), roof ponds and solar rooms. These options are not being considered for this design and are beyond the scope of this thesis. The Cheyenne and Arapaho Tribal College is designed with maximum south-facing glass while being completely bermed with earth on the northwest, north and northeast sides. The intent of the design is to provide at least 50% of the needed heating with effective passive solar energy while sheltering the building from prevailing winter winds.

3.3.3 Geothermal Heating and Cooling

The word geothermal has two parts: geo, meaning Earth, and thermal, meaning heat. Thus, geothermal concerns using heat from the Earth for both heating and cooling buildings. Geothermal heat pumps make use of the more moderate and more constant temperatures of the earth to bring indoor ambient temperatures to a level of comfort more efficiently and less expensively than would be possible through other sources of energy. Some green architects are designing homes and buildings that are at least partially subterranean, to take advantage of that stable temperature and reduce the need for mechanical HVAC (heating, ventilation and air-conditioning) (Egg p.8). Such designs

already have a decreased demand for heating and air conditioning. The addition of high thermal mass in the form of concrete, needed for sub-grade structures, foundations and slabs, will further decrease the need for auxiliary heat or cooling as the concrete, like the Earth, acts to store heat.

There are two types of geothermal systems that are used to move heat either to or from the Earth: open and closed-loop. "Open systems use water directly from wells, abandoned mines, and surface water found in ponds, lakes, and streams and can be installed where adequate supply or suitable water is available and where open discharge is feasible. A closed-loop system circulates a secondary fluid (water or a water-based antifreeze solution) through a continuous sealed and buried piping arrangement to transfer heat to and from the Earth" (Bose, 1997, p.1). During the winter, the fluid collects heat from the Earth and carries it through the system and into the building. During the summer, the system reverses to cool by pulling heat from the building, carrying it through the system, and placing it in the ground.

The energy available in the Earth's crust for use by a heat pump system is stored solar energy. "Energy is transferred constantly to and from the Earth's surface by solar radiation, rainfall, wind, etc." (Bose, 1997, p.6). As a consequence of this solar energy input, the Earth's temperature at depths greater than 30 feet approaches the annual average temperature which for Weatherford, Oklahoma is 59.7 degrees Fahrenheit.

"For cooling, because we are not using an outside fan, which passes already hot summer air over a coil that is sitting in the summer sun, we are saving energy" (Egg, 2011, p.9). The amount of savings is determined by the difference between the outside air and the temperature of the ground. This difference could be between 10 and 25 degrees in summer and up to 50 or more degrees in the winter. These basic factors, combined with other variables, provide virtually free energy (with minimal energy used for the pump). "Up to 80% of the cooling and heating needs of a building can readily come free from the constant temperature of the Earth – we're just moving it" (Egg, 2011, p.9). The reason that 80% is the usual figure given is that the electricity it takes to run the geothermal system usually accounts for 20% of the cost it would otherwise take to heat or cool a building. In the case of the Tribal College, this 20% would disappear with the energy generated by the wind turbines.

“This concept is called an earth-coupled or ground-source system because it uses the surrounding ground as a heat sink and a heat storage medium” (Egg, 2011, p.10). Earth-coupled systems typically encompass all of the components that are part of a standard climate control system: heating, cooling, humidity control, zoning, air quality, air changes, and so forth. “The reversible heat pump has been a standard design for all climates where air conditioning, as well as heating, is essential” (Ochsner, 2008, p.90). For little additional cost, a standard add-on is available for both ground source and water heat pumps, enabling a reverse in the flow of refrigerant or water for cooling in the summer months.

Geothermal heating and cooling is not as well-known as it should be. It has several key advantages that are steadily gaining popularity. In fact, “more than 1 million earth-coupled heat pumps have been installed in the United States, according to the Stella Group, which is a marketing firm for alternative energy. These are split evenly between residential and commercial buildings. Priority Metrics Group predicts a growth rate of 32% for geothermal AC to continue for the next few years, with the market exceeding \$10 billion by 2013” (Egg p.10).

One of the advantages of geothermal heating and cooling is that it provides a very steady, even temperature and humidity control without the sudden blasts of hot or cold air that accompany conventional systems as they switch on and off. Another advantage is that these systems reduce peak demand from the power companies during the hottest (or coldest) times of the day. “The U.S. Department of Energy has reported that a 400 megawatt natural gas turbine (electric) generator could be taken offline for every 99,500 homes or 1400 buildings of 100,000 square feet converted to geothermal heat pumps” (Egg, 2011, p.12).

The cooling process involves extracting heat energy from the air in the building and moving it into the Earth. Transferring heat from the building into the Earth requires a cycle of expansion, compression, condensation and evaporation. A refrigerant is used as the heat transfer medium. The cooling cycle begins as the compressor delivers refrigerant to the water-to-refrigerant heat exchanger. Heat from the refrigerant is absorbed by (rejected into) the low temperature source (earth loop fluid or well water), thereby cooling the refrigerant. The cold refrigerant then passes through a refrigerant-to-air heat exchanger. As warm,

humid air from the return air duct system passes over the cold air coil, the air is cooled and dehumidified, then returned into the building. The heat from the warm air returning to the unit is absorbed into the cold refrigerant, turning the refrigerant into a gas. The gaseous refrigerant is then returned to the compressor, where the process is repeated. Some of the refrigerant from the compressor is diverted into a separate refrigerant circuit, where hot water is generated and delivered to the hot water heater by way of a small pump.

The heating process involves the extraction of heat energy from the ground and moving it into the building. Transferring heat from the Earth into the building requires a cycle of evaporation, compression, condensation and expansion. A refrigerant is used as the heat transfer medium. The heating cycle begins as cold, liquid refrigerant passes through a water-to-refrigerant heat exchanger and absorbs heat from the low temperature source (earth loop fluid or well water). As the heat is absorbed, the refrigerant evaporates into a gas. This gaseous refrigerant then passes through a compressor, where it is pressurized, raising its temperature to over 180° F. The hot gas then circulates through the refrigerant-to-air heat exchanger, where heat is removed as the cooler return air passes over it. Now heated, this warm air is delivered into the building by way of the blower and duct system. Upon releasing its heat energy into the air, the refrigerant returns to the water-to-refrigerant heat exchanger, where the process is repeated. A by-product of the heating function is the production of hot water, delivered to the water heater by the way of a small pump.

“In some cases, rather than a closed-loop system of pipes in which a refrigerant is cycled, ground-water is pumped from the Earth and runs directly through the water-to-refrigerant exchanger, and is injected back into the same water source” (Egg, 2011, p.24). “If groundwater is available, the highest coefficient of performance can be achieved” (Ochsner, 2008, p.36). Groundwater remains at a nearly constant temperature of 8 to 12 degrees Celsius (46 to 54 Fahrenheit). The result is that, “in comparison to other heat sources, the temperature increase required for the useful heating purposes is relatively small” (Ochsner, 2008, p.63). The best groundwater heat source system is an open system and may require approval by local code officials. For the Cheyenne and Arapaho Tribal College, storm water runoff is filtered and collected in a cistern under the academic building. The water from this cistern, which is contained in concrete and summarily connected to the Earth, will be used as the heat sink or source in a closed-loop system. In this way, pristine

groundwater is not disturbed and used in the system. Instead, gray water that would normally run off the site, as well as treated water from the water management system (described in the next section) is used to heat and cool the building providing both a fossil-fuel-free heating and cooling source, plus a solution for managing storm water runoff on the site.

To provide a proper underground cistern in which to store storm water runoff, concrete is to be used. The concrete, lined with a waterproof membrane, not only contains the water and will resist the weight and pressure of large volumes, but also acts as a medium between the Earth and the water by absorbing heat from or injecting heat into the water. Therefore, concrete is the main material required to perform this task.

3.3.4 Water Management

The Cheyenne and Arapaho Tribal College will employ a “Living Machine” in the treatment and management of wastewater. Treating wastewater on-site rather than relying on the sewer system and municipal water treatment plants will assist in conserving and recycling water, as well as reducing the amount of water consumed by the Tribal College. This system should be used as an educational tool for students and the community alike.

Resembling a small-scale tropical forest, John Todd’s attractive solution to wastewater management uses plants to clean up water. “Consisting of a series of ecosystems that work together to break down water contaminants, Todd’s approach offers a natural and eco-friendly alternative to costly traditional water treatment plants” (Chen 2008). Converting sewer sludge to fresh water is no easy job. Traditional treatment plants consume massive amounts of money, energy, and resources. “John Todd’s innovative solution for wastewater management re-envisioned the process as an eco-conscious endeavor, conserving water and reducing overall treatment costs with minimal sludge disposal, water purchases, sewer surcharges, and chemical use” (Chen 2008). Invented by Dr. John Todd, of “Living Machines, Inc.,” the “Living Machine” system is one of several ecological methods for treating wastewater. “Living Machine” is a registered trademark of “Living Machines, Inc.” In addition, companies such as “Clearstream” and “Eco-Machine” also provide this type of constructed wetland system for treating wastewater.

The “Living Machine” treats wastewater using a system of engineered ecologies. Since the technology uses “helpful bacteria, fungi, plants, snails, clams and fish that thrive by breaking down and digesting pollutants”, selecting and then cultivating diverse communities is key in order for all compounds to be treated (Chen 2008). Part natural and part man-made, these natural resources are organized to transform water from dirty to clean. For this ecology to thrive it requires light and minimum temperatures above 45°F. Therefore, in cold to moderate climates such as Oklahoma, Living Machine systems are constructed in a greenhouse.

The main part of the “Living Machine” system will be located in a solarium downhill from the academic building (its location is yet to be determined). The raw wastewater flows from the building into two septic tanks. No aeration is provided in these reactors in order to create anaerobic conditions and to allow separation of solids from dissolved and suspended waste components. The primary purpose of the anaerobic reactor is to remove settle-able solids and oil and grease. Also, a significant portion of the incoming organic material is removed without using aeration. The still condition in the anaerobic reactor allows solids in the effluent wastewater to settle which are stored for later removal. Oil and grease in the effluent are retained in the anaerobic reactor, preventing them from being a nuisance in the downstream processes. Organic solids and oil and grease retained in the anaerobic reactor will partially degrade before removal, thereby reducing pumping and disposal requirements.

Following the anaerobic reactors, wastewater flows through two closed aerobic reactors - also buried outside - where the remaining organic compounds are further degraded. The purpose of this reactor is to remove a large fraction of the organic material in the effluent from the anoxic reactor and to strip odorous gases from the wastewater. Some conversion of organic and ammonia nitrogen to nitrate (nitrification) occurs in this reactor. The covered aerobic reactor will be aerated with fine bubbles diffusers to provide the required oxygen for treatment and to keep the contents mixed. Venting of the gases from the covered aerobic reactor is passed through activated carbon filters.

After flowing through the closed anaerobic and aerobic reactors, wastewater enters the “Living Machine” solarium and flows through three open aerobic reactors called hydroponic reactors. In the most basic design, waste-water pulses through a minimum of three different ecological systems that process and filter it in different ways. Each ecological

system is isolated from the others so that it can treat waste-water based on its own unique needs, after which the water cycles on to the next community. “The magic lies in understanding how the organisms interact and combining them properly so that they can soak up the nutrients they love, helping them grow while providing clean – if not drinkable – water” (Chen 2008). Wastewater then flows through a constructed wetland surrounding the open aerobic tanks for final polishing. Ultraviolet disinfection provides excellent pathogen inactivation without the use of toxic compounds and does not produce undesirable byproduct compounds in the treatment effluent. Ultraviolet disinfection is the final step prior to the treated wastewater being returned to the building for use in flushing toilets and for irrigation. This completes a continuous loop whereupon the same water is used continuously for the removal of waste.

Since their inception, these eco-friendly contraptions have seen a variety of applications. “Living Machine” systems have proven to be very durable and reliable nationally and internationally. “They have been used very effectively on much larger scales by businesses, schools, and government agencies in climates as diverse as the maritime Pacific Northwest, the arid Mojave Desert, and temperate (seasonally very cold) New England” (Hurd, 2006, p.1).

Their rather remarkable use of living organisms makes them a shoe-in for use as an educational tool, as they are at Oberlin College in Oberlin, Ohio; Clatsop Community College in Astoria, Oregon; and The Ethel M. Chocolate Factory in Henderson, Nevada. In the case of Ethel M, the system – installed in 1995 – handles 32,000 gallons per day of wastewater. Costly surcharges for disposing of high-strength confectionary wastewater were adding to operating expenses at this facility. “Ethel M Chocolates decided to install a ‘Living Machine’ system to cut expenses. The system reclaims the processed wastewater and reuses it for onsite landscape irrigation. Sludge is also treated and reused on-site with a composting sludge disposal reed bed, making this a zero discharge facility” (Hurd, 2006, p.2).

Along with its primary function of treating wastewater and its identification as a model for sustainability and ecological design, the “Living Machine” system will be a teaching tool for present and future CATC students. It will be a working classroom for sustainability and ecological design as well as other science and environmental coursework.

"The integration of architecture, ecology and landscape ensures that students come away with the understanding that materials and design can be handled much more intelligently," says Todd. "The bottom line is that resources are saved for future generations in a way that teaches the generations of today" (Chen 2008).

3.3.6 Earth Integration and Green Roofs

The topic of green roofs and Earth-integration is closely connected to ecological correctness. Integrating the Tribal College academic building into the Earth is not only a nod to culture, but also an incredibly sustainable approach to energy conservation. This is not a case of chasing the fame of being recognized as "green" – it is the social and ecological correctness of sculpting architecture in harmony with the land. There is no good reason why houses, offices, schools and the Earth should be thought of as separate entities. "It may be traditional to say that our houses should sit on top of the Earth, but it isn't an eternal verity and, in fact, it doesn't make much sense in today's energy-hungry world" (Edelhart, 1982, p.xv). If buildings and Earth are separated, then they are in effect being built in the air. Air itself is a thief responsible for the loss of heat and moisture from buildings. Air erodes their surfaces, loosens their joints, makes them inefficient, and shortens their lives. Conversely, the Earth serves as a blanket for a building. It stores heat, buffers the walls from cold, rain and wind. "A building designed in harmony with the Earth will be far longer-lasting and inexpensive to operate than any surface building of similar size" (Edelhart, 1982, p.xv). There are numerous advantages to this approach, as well as some disadvantages. In addition to factual concerns there are also psychological concerns that accompany "living" underground.

One main reason for Earth-integrated buildings and green roofs is environmental. They are most valuable in the mitigation and even elimination of water runoff problems associated with the development of a site. "Current research at North Carolina State University in storm water management suggests that green roofs with at least 4 inches of substrate (soil) retain as much as 60% of all rainwater, which has tremendous potential for addressing storm water runoff and water quality" (Snodgrass, 2006, p.21). Green roofs and Earth-integration offer vegetated areas that have both aesthetic and practical benefits. Planting areas otherwise lost to development soften and green the area, and transpose the ground taken by the building's footprint to the roof. "Vegetation does more than offer

aesthetic qualities, it provides habitat for birds and insects, sequesters carbon dioxide and other pollutants, purifies the air, produces oxygen, and returns moisture and coolness to the air through evapotranspiration” (Snodgrass, 2006, p.22).

Another main reason for turning to the Earth, which is even more compelling for the non-tree-hugger, is economics. “The reason underground structures save so much energy is not because Earth is a good insulator. In fact, Earth is a lousy insulator. Urethane foam is perhaps ten to twenty times as good. But, Earth is a great moderator of temperature change” (Edelhart, 1982, p.7). The Earth does not react as fast or as severely to temperature change as the air does. “If, for instance, air temperature on the surface ranges from 0 to 95 degrees Fahrenheit, four yards (12 feet) down the temperature of the Earth will vary only from 50 to 65 degrees Fahrenheit” (Edelhart, 1982, p.7). The Earth serves as a great moderator of temperature acting as a warmer in the winter and as a cooler in the summer which tremendously reduces the load on heating and cooling systems.

Another enticing feature of Earth-sheltered buildings is their incredible durability and stability. Jay Swayze notes that “it’s nature that destroys shelter, even with continuous maintenance. By putting dwellings underground, we are attempting to put shelter in harmony with nature. “Protected from the ravages of weather, an underground structure can last forever” (Edelhart, 1982, p.7). Beneath the surface of the Earth, buildings avoid the onslaughts of tornados, hurricanes, and other surface destruction. “Many Earth-shelter homes are already in the dirt in Oklahoma. The reason for this is that they can’t be blown over by that state’s frequent, violent tornadoes” (Edelhart, 1982, p.123). In fact, the safest place during a tornado or wind storm is inside an Earth-sheltered building. During a tornado, the incredible and sudden low pressure outside the building, as opposed to high pressure inside, cause any glass that breaks to explode outward and not inward as many fear. “In Oklahoma, two reasons for a surge in Earth-sheltered building activity were energy conservation for heating and cooling and protection against inclement weather was also cited since tornados and heavy winds have repeatedly caused extensive damage across the prairies of Oklahoma, it is not surprising that storm protection ranked third” (Boyer, 1987, p.14).

On the surface, insulating a building involves wrapping the entire structure as tightly and completely as possible. Outside air steals heat and the sun pours unwanted heat into

the structure. The envelope of occupied space must be thoroughly separated from the environment. Under a blanket of Earth, the situation is different. “The Earth environment, too, bleeds heat from the warmer interior, but at a much slower pace than the air” (Edelhart, 1982, p.69). In addition, the Earth doesn’t blow away the heat like the wind – it stays put. Later when the building cools, the soil can return some of the heat to the building. “This gentle transfer is the key to earth-sheltered energy savings” (Edelhart, 1982, p.69). Earth sheltered buildings need to be insulated well enough to keep from losing significant amounts of heat to the soil in the winter months, yet loosely enough to allow for the moderation of the temperature with the surrounding soil. Owners of Earth-sheltered buildings expect substantial opportunities for energy conservation. According to Boyer (1987), records of metered energy usage support this contention from a voluntary study conducted in Oklahoma. Respondents, all of whom resided in central Oklahoma, submitted their energy bills. There were 20 above-ground all-electric homes selected randomly from respondents, as well as 6 Earth-shelter homes that were newly constructed at the time. After comparing the data, the average reduction in total energy use was 40% (higher if only heating and cooling energy are considered and lighting is left out), which agrees with owner perceptions of earth-sheltered building performance (p.170).

Solar heating and Earth-sheltered design are natural partners. In fact, “the strengths of Earth-sheltering shore up the weak spots in solar heating systems, and vice versa, producing a combination that performs better than either unit separately” (Edelhart, 1982, p.86). In an Earth-sheltered building, the total amount of heat needed is far less than would be for a surface building. “Another coincidence between Earth-sheltering and passive solar systems in particular is the enormous thermal mass of underground buildings” (Edelhart, 1982, p.86). The need for strong reinforced concrete construction places thermal mass at the ready to receive solar gain and to store heat. So an Earth-sheltered building puts whatever heat the sun provides to better use than a surface building and needs less heat input overall to maintain indoor comfort.

What does it feel like to live beneath the Earth? “Experts agree that the most alienating underground environment is the enclosed, windowless cavern” (Edelhart, 1982, p.125). “The greatest deterrent to investigating and building earthen structures is psychological” (Klodt, 1985, p.12). The ability to live and work at peak efficiency and happiness in underground environments is linked to the sense of space and openness that

can be designed into the place. In addition, passive solar systems require expanses of south glass. Designing the spaces so that the majority of them have access to views or natural light coming through these windows is another way of alleviating the feeling of being underground. "In most Earth shelters it is difficult to realize that you are below ground, and that there is earth on the roof" (Klodt, 1985, p.12). Quality of light in earth shelters is different than that on the ground. It tends to be "more directed – streaming through the glass-filled south wall but merely trickling through skylights – and brightness levels can vary; the sense of the sun passing overhead is much stronger than at the surface" (Edelhart, 1982, p.127).

With educational institutions, plummeting budgets dictate how a new building or campus will be constructed. They have to listen seriously to any idea that won't cost too much to build and will cost even less to operate. "In Oklahoma, 27 schools are at least partially underground and 15 more have bermed walls" (Edelhart, 1982, p.169). Many benefits have been identified including a lack of outside noise that contributes to increased attention spans, decreased revenue requirements for energy and maintenance, and a sense of security. "The Oklahoma experience did show that construction costs for the schools were slightly higher than comparable surface structures" (Edelhart, 1982, p.170). However, while initial costs were higher for the construction of the buildings, they were offset substantially by long-term savings in maintenance and energy consumption.

Producing a design that integrates the building into the Earth can save substantial amounts of energy for heating and cooling. In addition, this integration couples with passive solar heating in perfect harmony to further reduce the need for energy consumption. With a sloping site and the ability to berm into the Earth, as well as maintain an architectural and sculptural presence, the Cheyenne and Arapaho Tribal College will not only benefit from temperature moderation but also from the ability to connect from the interior to the outside world. Integrating buildings into the Earth may one day replace above-ground buildings that are literally built up in the air. "It is also possible that we might even discard our tendency to create 'pedestal architecture' in favor of being concerned about designing the 'place' and not just the building" (Edelhart, 1982, p.20).

3.4 Goals, Systems and Material Selection

This design is more than just a building where teaching takes place, the Cheyenne and Arapaho Tribal College will be a building that teaches. By virtue of its design concepts, systems, and environmental consciousness, students will learn the latest in environmental technologies, ecological competence and mindfulness of place.

With cultural as well as environmental considerations in mind, material selection is exceedingly simple. For Earth-integration, passive solar heating, and the use of a “Living Machine” for wastewater management, steel reinforced concrete and glass are the best choices. Geothermal heating and cooling as well as wind turbines do not require specific materials. Instead, they work in harmony with the passive systems that do require specific construction materials. Even though building materials can and do require energy to produce, if used in the correct spot and in the correct manner, they can end up being environmentally sustainable.

4 Materials in Depth

4.1 Introduction to Material Selection

Traditionally materials were chosen for building based on factors such as local availability and function, but the global market and cheap transportation have given designers the possibility of making selections from a much larger palate of materials. Many of these decisions are based on fashion, appearance, and cost rather than function. More recently, however, the environmental implications of some materials have become apparent, and have shown this approach to be unsustainable. Principal criteria for sustainable materials should be suitability in terms of performance and durability, relative impact on the environment, ability to reduce its own impact through its use, and health hazards with using the material.

One of the focuses when it comes to the sustainability of a building material is its embodied energy. “Embodied energy is defined as the energy consumed by all process associated with the production and use of a material or assembly, from the acquisition of natural resources to its final refuse or demolition” (Spence, 2011, p.63). Typically this is measured as a quantity of non-renewable energy per unit of building material or component in either mega Joules (MJ) or British Thermal Units (BTU) per unit of weight (kilograms or tons) or area (square footage) of a material. “Published figures of embodied energy should be used with caution because values change depending on a variety of factors” (Spence, 2011, p.64).

It is also important to compare a building’s embodied energy (in materials) against its operational energy. The energy used by many buildings during their lifetime is far greater than the embodied energy content of their materials. However, in the future, as energy-efficiency measures become the norm, the embodied energy percentage will constitute an increasingly significant part of the lifetime energy consumption of the building. If operational energy can be generated on-site without negative environmental effects, the embodied energy of the materials could theoretically constitute 100% of the total.

Longevity is a key in sustainable use of materials and steel, concrete and glass as building materials fit the bill in this category. “A long use life can offset the substantial resource use and emissions and waste resulting from a material’s manufacture” (Calkins,

2009, p.327). If a product or structure remains for many years in the use phase, the negative impacts from its production can be amortized over a longer period, reducing their intensity.

Often the energy used in operating a building can be readily measured, whereas the embodied energy of building materials can often be difficult to calculate. Therefore, a life cycle analysis (LCA) is often needed to get a full picture of the energy required by a building from raw materials to operation to demolition. This life cycle begins with the extraction of the natural resources required to manufacture materials for use in the construction industry. In this, both extraction and transportation are taken into account. From there, the energy of manufacturing the material is calculated as the next stage and usually accounts for the largest expenditure of energy in the life cycle of a building product. This is followed by on-site construction, which is technically an extension of the manufacturing process as individual components come together in the assembly of an entire structure. "Once the building is complete and occupied, operating energy is calculated, taking into account functions such as heating, cooling, lighting, and water use" (Spence, 2011, p.64). This phase of energy use is the most intense as nearly 85% of the embodied energy in a building comes in the form of operating energy over a 100 year life span. Only 15% of the total lifetime energy is embodied in materials. Demolition is the final stage that is measured and often means the end of the life cycle for many materials. However, an "increasing amount of materials face subsequent recycling or reuse" (Spence, 2011, p.64). The information cited here is meant as a guideline and generally uses the most common methods of production and transportation, as well as average distances for transportation.

The materials being presented in detail include concrete, glass, steel and bamboo. These are the four main building materials that make up the structure and building envelope of the Cheyenne and Arapaho Tribal College, listed in order of importance and also in descending amounts required by the design. Background information is presented on each material, followed by the acquisition and processing of the raw materials that are used in the production process. Following the raw materials, the production, construction, use, and finally demolition and recycling phases are discussed. In each of these categories, when available, information about embodied energy is presented. In the final section of this chapter entitled *Life Cycle*, a traditional building of the same square footage is compared to

the Cheyenne and Arapaho Tribal College design to show the amount of energy that is saved, and even “given back” over the 100-year (plus) life expectancy of the building.

4.2 Concrete

Over the last century, concrete has become the most important building material throughout the world. “Concrete is the most commonly used construction material in the world, and after water is the second most consumed product on the planet” (Calkins, 2009, p. 103). This popularity is due to the fact that concrete is produced from widely available and abundant natural materials that are found in all parts of the world, and to the fact that it is an extremely versatile material that allows architects to design with any shape or form imaginable. Localized depletion of some of these resources may occur, although as with other raw materials, depletion is more usually defined by the quality of remaining resources rather than by absolute depletion (Demkin, 1998, MAT 03100 p.10). Concrete has been the focus of criticism from the green movement in recent years due to its emission of large amounts of carbon dioxide in the manufacturing process. However, it is an extremely durable material that, if used properly, can offset its initial production of greenhouse gasses through its longevity and thermal properties. In addition, there are emerging practices and technologies that are assisting in further offsetting the effects of concrete and cement production.

“The production of concrete amounts to 1.48 – 2.95 tons per capita annually in the industrialized world” (Glavind, 2009, p.120). Thus, the concrete industry and its suppliers make up a large portion of the building sector. Any improvements made in the sustainability of concrete and its industry will lead to vast improvements in the building sector in general. “For instance, Portland cement which is the primary ingredient and binder in concrete is produced in large quantities around the world which amounts to 1.6 billion tons annually” (Glavind, 2009, p.120). With this, the production of one ton of cement generates approximately one ton (or 2000 pounds) of carbon dioxide emissions. With the construction industry still growing, and the use of concrete expanding, there is a challenge in meeting the demand for cement and concrete while reducing global carbon dioxide emissions. In many parts of the world, extreme weather patterns are occurring with greater frequency. Most scientists believe that this phenomenon is associated with the high emission rates of greenhouse gases, primarily carbon dioxide, the environmental concentrations of which have

increased from 280 to 370 parts per million mainly during the industrial age. “The transportation industry and the Portland cement industry happen to be the two largest producers of carbon dioxide - the latter is responsible for approximately 7% of the world’s carbon dioxide emissions” (Mehta, 2001, p.1).

Concrete is a mixture of constituents, each with embodied energy associated with the extraction and processing of the raw materials before they ever reach the ready-mix plant to be combined into the final product. “A typical mix of concrete contains 10% Portland cement, 40% coarse aggregate (gravel), 30% fine aggregate (sand), 15% water and 5% air” (Demkin, 1998, MAT 03100 p.17). This mix will vary and change depending on the application and use of the finished concrete, its exposure to the elements and freeze/thaw cycles, and the addition of other contents such as fly ash and recycled aggregates.

The image often associated with the construction industry is one of environmental degradation especially when it includes heavy concrete. This image is often based on ignorance and lack of knowledge. There is an overwhelming volume of information available on concrete and the environment. The issue is most of this information is fragmented and conflicting. The ability to discern between scientific knowledge and industry marketing is difficult. The concrete industry is well aware of the environmental impacts and benefits of their products and in order to sell a product the positive virtues are most often cited as a sound reason for its use.

When determining the environmental impact of concrete structures, considering all life cycle phases from cradle to grave (or cradle to cradle as the case may be) is essential in determining the sustainability of the material. Very often an assessment of a building material focuses on the embodied energy and initial carbon dioxide emission of the manufacturing process. However, the longevity of the material as well as the properties the material possesses while in use is crucial to arriving at a proper measurement of sustainability. Therefore, all life cycle phases including extraction of raw materials, production, construction, use and finally demolition and recycling must be included in the overall judgment of sustainability. In the case of concrete, the issue of resource consumption is insignificant because of the abundance of the raw materials. One exception is the “steel used for reinforcing which requires the extraction and use of scarce resources

such as chromium, nickel and molybdenum” (Glavind, 2009, p.122). Today, most steel used in the construction industry is manufactured and fabricated from reclaimed and recycled steel rather than virgin materials.

The primary concern with energy consumption is in the production of cement clinker and steel reinforcement. Added to production energy is the amount consumed by construction, demolition, recycling and transportation of materials for production or use in distant locations. Finally, the life cycle, that is the use and operation of the building over its lifetime, where energy use is of most concern, is often ignored in assessing the sustainability of a building project.

Concrete is composed of a number of different raw materials and the environmental impact of the material is a complex equation governed by the individual impacts from each of the ingredients separately, as well as the combined effect when they are mixed together in to a final product. The aggregate portion of concrete generally accounts for 70 – 75% of its volume and therefore the environmental issues of aggregate production strongly influence concrete production. Furthermore, cement production is associated with high energy consumption and carbon dioxide emissions. Thus, “the sustainability of concrete as a building material is strongly influenced by the cement industry and the aggregate industry” (Glavind, 2009, p.124). Since concrete is reinforced by the use of steel bars, stirrups and wire mesh, this also needs to be taken into account in a total environmental impact statement. The amount of steel used in a reinforced concrete building varies with design and purpose, but generally comprises 0.8% to 1.5% of its total volume. For the purpose of separating materials, steel is analyzed as a material separate from concrete in a subsequent section.

4.2.1 Cement

The most important environmental effects of cement production can be divided into the extraction of raw materials, the use of energy in production and emissions of carbon dioxide. “In addition to carbon dioxide release and energy use, mining of limestone, the major raw material in cement, can cause habitat destruction, increased runoff, and pollutant releases to air and water” (Calkins, 2009, p.104). Some limestone mining operations are abandoning open pit mining techniques in favor of underground mining. This may reduce some habitat and pollution impacts, yet may increase the cost of producing cement.

Portland cement is a fine, pulverized material consisting of compounds of lime, iron, silica, and alumina and makes up approximately 10% of the volume in a concrete mix. “The exact composition of different types of Portland cement varies, but the composition of Type I, Normal, is 60 – 66% lime, 19 – 25% silica, 3 – 8% alumina, 1 – 5% iron, 0 – 5% magnesia and 1 – 3% sulfur trioxide” (Spence, 2011, p.111). The manufacture of Portland cement requires the combination of these elements in proper proportion under carefully controlled conditions. The lime in Portland cement is commonly derived from limestone, marble, marl, or seashells. Iron, silica, and alumina are obtained from mining clay containing these elements. “The raw material components of Portland cement are obtained largely through open pit mining” (Demkin, 1998, MAT 03100 p.8). In the quarry, limestone is generally obtained by blasting with explosives and the broken rock is hauled away in large dump trucks. In most cases, the cement plant is adjacent to the quarry. With this in mind, “raw materials are trucked to the crushing equipment which is rarely more than 10 or 15 miles away. When greater distances are involved, the rock is carried by barge on inland waterways” (Demkin, 1998, MAT 03100 p.11). These ingredients are crushed in a primary crusher and sent through a screen. Those pieces not falling through are sent to a secondary crusher.

After crushing, either a wet or a dry process is used to produce the final cement. The dry process grinds the raw materials to a powder, blends them in mixing silos, and moves them to a kiln. This process accounts for 75% of the cement production in the United States. In the wet process (the remaining 25%), the ground materials are mixed with water to form a slurry, blended, and moved to a kiln. The kiln is a rotating cylinder operating at 2600 – 3000 degrees Fahrenheit that burns the materials into a clinker. The clinker is cooled, a small amount of gypsum added, and ground into a very fine powder. An average of almost 5 million BTUs is used to produce one ton of clinker. In 2004, the cement sector of the building industry consumed 422 trillion BTUs of energy, which amounts to 2% of the total energy consumption by U.S. manufacturing. “Cement composes about 10% of a typical concrete mix, but accounts for 92% of its energy demand” (Calkins, 2009, p.105).

Acquiring the raw materials for Portland cement production can create several environmental problems. “The environmental effects of surface mining may include runoff from tailings waste, which may lead to increased turbidity of surface waters, increased biological oxygen demand, de-oxygenation of aquatic habitats, and possible fish kill”

(Demkin, 1998, MAT 03100 p.10). Additional impacts from mining include land disturbance and alteration of wildlife habitat. One step that is being taken to mitigate the loss of land area to mining is to quarry deeper rather than to excavate a larger surface area. This is resulting in a lower quality material, which is the trade-off for leaving surrounding lands and habitats un-disturbed.

As previously stated, in modern cement production, one ton of Portland cement clinker produces approximately one ton of carbon dioxide emissions. “Approximately 45% of this is from the calcination process which is the de-carbonation of the limestone” (Glavind, 2009, p.124) with the remaining 55% resulting from fossil fuel combustion. “Worldwide, the cement sector is responsible for about 7% of all man-made emissions of carbon dioxide, the primary gas that drives global climate change” (Calkins, 2009, p.105). Unfortunately, it is impossible to convert limestone (CaCO_3) to calcium oxide (CaO) and then clinker without generating carbon dioxide. This is emitted into the atmosphere; however, research is being conducted in an effort to sequester it. Some methods that cement producers can use to reduce carbon dioxide emissions include using the dry process, which uses less energy than the wet process. “New plants in the United States use the dry process and some older plants have converted from wet to dry” (Calkins, 2009, p.106). Other ways to reduce carbon dioxide emissions include increasing the use of blended cements that include fly ash as well as using alternative fuels and more fuel-efficient processes for manufacturing Portland cement.

Traditionally, fossil fuels such as coal and oil have been used in the burning process. Over the past few decades, the cement industry has reduced the environmental impact from cement production. “The fact that producing cement is energy intensive has an advantage: the potential for destroying hazardous waste materials such as used motor oil, spent solvents, paint residues, cleaning fluids, scrap tires and municipal solid waste” (Glavind, 2009, p.124). According to the Concrete Joint Sustainability Initiative website, the alternative fuels reduce fossil fuel use and in some cases provide treatment to otherwise difficult waste streams. Examples include waste tires, which are notoriously common, difficult to recycle, and dangerous to landfill. “Using waste as a fuel reduces the need for mining of new fuels as well as the accompanying pollution and depletion of resources” (Demkin, 1998, MAT 03100 p. 7). The U.S. generates 300 million scrap tires annually, which contain 25% more energy per pound than coal. The CJSI claims that EPA testing

has confirmed that they burn as clean as traditional fuels, or cleaner. According to the EPA's website, cement kilns appear to be very suitable for disposing of waste tires because these furnaces operate at very high temperatures and have long residence times. Kiln temperatures are typically in excess of 2,600 degrees Fahrenheit. High temperatures, long residence times, and an adequate supply of oxygen assure complete burnout of organics, which minimizes the formation of dioxins and furans, a primary consideration in solid waste combustion (EPA). Cement manufacturing utilizes very high temperatures so complete combustion occurs, capable of destroying many of the toxins of concern. In 2008, 68% of U.S. cement plants used some form of alternative fuel - which accounted for 10% of energy consumption.

The reason these waste materials can be destroyed safely is the extremely high temperatures used in the rotary kiln results in complete combustion with low pollution emissions. This is in sharp contrast to the incomplete combustion achieved in municipal solid waste incinerators which operate at much lower temperatures. "Indeed, for some chemicals, thermal destruction in a cement kiln is the safest method of disposal" (Glavind, 2009, p.124). Fuels derived from waste comprise a significant and growing part of the energy used in the production of cement. "In 2002, fifteen plants burned waste oil and forty plants burned scrap tires, solvents, unrecyclable plastics and other waste materials" (Calkins, 2009, p.105). In this way, fossil fuels are conserved and waste materials are diverted from landfills and hazard waste disposal sites. The use of these waste materials is a positive step in the production of cement, yet it must be noted that the use of waste-derived fuels in no way reduces the carbon dioxide emissions of the production process, but merely directs wastes away from landfills.

"One hundred fourteen plants produce cement in thirty-seven states at locations with adequate supplies of the raw materials" (Calkins, 2009, p.104). The major advantage of having so many plants is the transportation distance for Portland cement is low and though it is a major contributor to environmental problems, the environmental impact of transporting this constituent is relatively insignificant. "Most Portland cement is shipped in bulk, in railroad cars or large trailers designed especially for this material" (Spence, 2011, p.111). According to the Environmental Protection Agency's 1997 Portland Cement Association Summary Report, the closest cement plant to the Tribal College site is a mid-size plant run by Holnam, Inc. located in Ada, Oklahoma – a distance of 152 highway miles. This keeps

the supply within a 500-mile sustainable radius of the building site. This is an important concept in sustainable building as it keeps supplies of materials local and greatly reduces transportation costs and its associated environmental effects.

The energy consumed in the production of Portland cement is largely in the form of fuels consumed to power equipment used for mining, crushing, hauling, beneficiation, and processing the raw materials. "Recent data (1998) from the industry indicates that cement production requires 2401 BTUs per pound or 4.8 million BTUs (5064 MJ) per ton of cement" (Demkin, 1998, MAT 03100 p.16). An additional 148 BTUs per pound (0.156 MJ per pound) are required for hauling the cement to the job site. Since Portland cement makes up 10% of the mixture for concrete, the embodied energy of the amount of Portland cement in one ton of concrete is equal to 480,000 BTUs (506.4 MJ).

4.2.2 Fly Ash

Fly ash is a pozzolana that is a material that reacts with lime to form a hardened mass. "By mixing a red volcanic powder, found at Pozzuoli near Naples, with lime the Romans discovered in 75 B.C. that a form of concrete could be created. Pozzolanic cements were first used at Pompeii in 55 B.C." (Sear, 2001, p.63). Gradually, concrete replaced the brick and stone that was used in traditional building. The dome of the Pantheon in Rome is an example of pozzolanic lightweight concrete which is over 50 meters in diameter. The concrete mixture used is a combination of a lightweight aggregate (pumice), with an air-entraining agent (animal blood) and a pozzolanic material (volcanic ash). This ash is the reason the Pantheon still stands and that the dome has such strength and rigidity. "In 1824, Joseph Aspdin obtained his patent for 'Portland cement.' Owing to the more rapid gain in strengths of Portland cement, pozzolanic of 'Roman cements' fell out of use" (Sear, 2001, p.63). Only recently has the use of ash returned to the art of producing concrete and has gained popularity in the recycling of industrial wastes that would otherwise be landfilled.

Blended cements have gained popularity in recent years for use in the construction industry. These are cements in which a percentage of the Portland cement is replaced by other pozzolanic materials. Particularly significant is the use of fly ash from coal-fired power plants. "Fly ash is a fine, glass-like powder recovered from the gases created by coal-fired power plants. U.S. power plants produce millions of tons of fly ash annually, much of it

discarded in landfills” (Spence, 2011, p.116). Fly ash consists of silica, alumina and iron and forms cement in the presence of water. When mixed with lime and water it forms a compound with properties very similar to Portland cement. “First discovered during the construction of the Hoover Dam, the material is now used frequently in concrete mixes” (Spence, 2011, p.116). The production of blended cements with fly ash content reduces the amount of carbon dioxide that is emitted in the production of cement by the same percentage as the substitution. Currently a fly ash content of 20% is common in blended cements, which reduces carbon dioxide emissions by a corresponding 20%. The carbon dioxide emissions of the coal-fired power plant cannot be included in the emissions for the fly ash content because it is a waste product of energy production and is captured by pollution control equipment in the power plant’s stacks. The use of fly ash in concrete also helps eliminate the need to dispose of these materials as waste products. “Any pollutants that result from the production of fly ash is not attributed to the life cycle of concrete” (Demkin, 1998, MAT 03100 p.12). As long as coal-fired power plants continue to operate, there will be a supply of fly ash that should be diverted from landfills by using it as a replacement for cement in the production of concrete. This diversion constitutes a green initiative that helps reduce the amount of landfill space taken unnecessarily. Fly ash from coal-fired power plants has been used for half a century in Europe and out of an annual production of 40 million tons half is used in the construction industry. “ Although the normal substitution rate is 10 – 20% (relative to cement weight), it is now possible to produce high-performance concrete mixtures containing 50% to 60% fly ash by mass of the blended cementitious material” (Mehta, 2003, p.3). With 50% fly ash added, the corresponding decrease in carbon dioxide emissions from cement is also 50%. This changes the earlier formula from one ton of carbon dioxide emitted per ton of cement to 0.5 tons (1000 pounds) per ton of cement produced – a significant reduction. In commercial practice, the dosage of fly ash is limited to 15%-20% by mass of the total cementitious material. “Usually, this amount has a beneficial effect on the workability and cost economy of concrete but it may not be enough to sufficiently improve the durability to sulfate attack, alkali-silica expansion, and thermal cracking” (Mehta, 2003, p.3). This means that while using fly ash at the accepted level may increase the overall strength of cast in place concrete, it does little to improve its durability. Fly ash is the supplementary cementitious material that is available in large quantities at the lowest material cost. Malhotra (2007) estimates that it is safe to say

that fly ash will be available in large quantities until at least the year 2050 (Glavind, 2009, p.127).

In addition to diverting waste materials from landfills, “there are many investigations and many years of experience documenting the fact that replacing cement with fly ash improves the technical performance of both fresh and hardened concrete” (Glavind, 2009, p.127). Fly ash improves the workability of fresh concrete making it easier to place as it flows easily into formwork and around reinforcing. Its use reduces water demand and increases workability of fresh concrete because the small particles of fly ash pack voids between larger cement particles with their spherical shapes acting like ball bearings. “These attributes make fly ash concrete easier to pump, work, consolidate, and place in complex forms” (Calkins, 2009, p.115). The use of fly ash also increases the durability and strength of hardened concrete by decreasing concrete permeability and mitigating expansion. The early strength of fly ash concrete is often lower than that of corresponding pure Portland cement concrete, yet long-term strength is increased. “The heat of hydration of fly ash concrete is low, making it well suited for mass concrete structures” (Glavind, 2009, p.127). The slower setting and hardening rate of concrete containing a high-volume of fly ash can be compensated for, to some extent, by reducing the water-cementitious materials ratio. Nevertheless, “for most structural applications, somewhat slower construction schedules ought to be acceptable when resource maximization, not labor productivity becomes the most important industry goal” (Mehta, 2003, p.62).

It is possible to substitute up to 50% of ordinary Portland cement with fly ash, and obtain adequate early-age strengths and similar or higher strengths at 28 days and later, when compared to those of a control ordinary Portland cement concrete of similar grade. However, for all grades of concrete, this can be done only by using a significantly lower water to cement ration for the fly ash concrete compared to that of the control concrete. Using high volume fly ash concrete therefore conserves water, another precious resource. Using M60 concrete, which is the top grade concrete using specific aggregates and high supervision in its mixing and placing, the following results were observed. “With 100% Portland cement and no fly ash, the 28-day compressive strength reached 60.6 MPa (8,787 psi) and a 91-day strength of 61.9 MPa (8,976 psi). The highest compressive strength resulted from a mix of 70% Portland cement and 30% fly ash substitution where the 28-day strength reached 68.1 MPa (9,875 psi) and a 91-day strength of 80.2 MPa (11,629 psi)”

(Bouzoubaa, 2007, p.316). Finally, the concrete containing a 50% mix of Portland cement and fly ash substitute yielded a slightly lower compressive strength of the 30% mix. However, it was still higher than ordinary Portland cement at 100%. The results yielded a 28-day compressive strength that was not measured as 50% fly ash content has not reached proper supportive strength at this time. "It is recommended that testing begin at 56 days. However, the 91-day overall compressive strength for the 50% substitution is 71.6 MPa (10,382 psi)" (Bouzoubaa, 2007, p.316). This is stronger and more durable than concrete made only with Portland cement and proves that fly ash content ultimately results in increased strength of the final product. Vibrating high-volume fly ash concrete containing 50% or more fly ash substitution will assist in minimizing voids in the concrete and will result in higher compressive strength. "Adopting the principle of minimum voids in the paste, mortar and aggregate, mix designs have been successfully used for concrete placed in floor slabs, structural basements and walls" (Sear, 2001, p.105). These concretes contain 40 – 60% fly ash by volume. "Other work, using the maximum packing, minimum porosity principle of compaction by vibration, have been designed for structural concrete with fly ash making up to 70% of the cementitious content by weight" (Sear, 2001, p.105). "This fly ash content, 70% substitution, yields a compressive strength effectively equal to pure Portland cement concrete which is 60 MPa (8,700 psi)" (Mehta, 2003, p.5).

"Because fly ash concrete reduces the need for water in the mix to attain good workability, there is less drying shrinkage and cracking from restraints such as rebar, welded-wire mesh, or formwork" (Calkins, 2009, p.116). This property makes it possible to achieve mix proportions with low porosity and low permeability. In addition, with slower set times, there is less thermal shrinkage and cracking from differential temperatures between the core and surface of the object. "Reduced cracking, smaller particles, more tightly filled voids, and reduced clumping of fly ash concrete all contribute to a reduction on permeability" (Calkins, 2009, p.116). This results in concrete that is more resistant to the corrosion of steel reinforcing and chemical attack from soils and pollution. "The majority of Portland pozzolana (fly ash) concrete mixes have a much greater resistance to pollution than pure Portland concrete" (Berge, 2000, p.197). In general, the resistance of a reinforced-concrete structure to corrosion, alkali aggregate expansion, sulfate and other forms of chemical attack depends on the water-tightness of the concrete. Sulfates in solution attack hardened cement in concrete. "The pH of soil or groundwater, water table and mobility of groundwater, and the concrete constituents, compaction and permeability are all influences

in this process” (Sear, 2001, p.97). Deterioration as a result of sulfate attack results in expansive pressures within concrete causing it to deteriorate or break apart. “Less lime will be present when cement is replaced by fly ash which means that less lime is available for the reaction with carbon dioxide and sulphate salts” (Balkema, 1992, p.95). The water-tightness is greatly influenced by the amount of mixing-water, type and amount of supplementary cementing materials, curing, and cracking resistance of concrete. “High-volume fly ash concrete mixtures, when properly cured, are able to provide excellent water-tightness and durability” (Mehta, 2001, p.4).

As a recycled, post-industrial material, fly ash use in concrete offers environmental advantages by diverting material from the waste stream, conserving virgin materials, and reducing the energy investment in processing them. “The use of fly ash is eligible for one recycled content credit in the LEED rating system, under the materials and resources category” (Spence, 2011, p.116). “From theoretical considerations and practical experience it has been determined that, with 50% or more cement replacement by fly ash, it is possible to produce sustainable, high-performance concrete mixtures that show high workability, high ultimate strength, and high durability” (Mehta, 2001, p.4). Therefore, high-volume fly ash concrete offers a holistic solution to the problem of meeting the increasing demands for concrete in the future. This is achieved in a sustainable manner and at a reduced or no-additional-cost manner. This reduces the environmental impact of two industries that are vital to economic development - namely the cement industry and the coal-fired power industry. “The technology of high-volume fly ash concrete is especially significant for countries like China and India, where, given the limited amount of financial and natural resources, the huge demand for concrete needed for infrastructure and housing can be easily met in a cost-effective and ecological manner (Mehta, 2003, p.11). Sear (2001) quotes Ed Abdun-Nur, who said, “concrete, which does not contain fly ash, belongs in a museum” (p.92). The benefits of fly ash concrete, listed in this section, should be cause to render traditional Portland cement concrete obsolete.

The energy consumed from the production of fly ash for use in the manufacturing of concrete is derived solely from the transportation of the ash from a power plant to the Portland cement plant. Any other energy or emissions are connected with the production of electric power and therefore cannot be attributed to the production of cement as fly ash is a waste product that is being diverted from the waste stream to beneficial use in concrete.

Due to the light weight of fly ash, transportation effects are negligible and the transport of this material to a landfill would be the same as its transportation to a cement manufacturing plant. This transportation energy, therefore, is not added into the amount to produce concrete.

4.2.3 Aggregate

Natural aggregate consists of manufactured crushed stone and sand which is created by mechanically crushing bedrock, or naturally occurring unconsolidated sand and gravel. It is a major component in concrete and is required in streets, highways, bridges, buildings, sidewalks, sewers, dams – just about every part of the built environment. “Aggregate is the world’s number one non-fuel mineral commodity in terms of both volume and value” (Langer, 2001, p.1). Natural sand and gravel resources are abundant throughout most parts of the world. The trend is moving toward recycling aggregate through crushing and manufacturing reclaimed concrete and masonry from demolished buildings. “Because there are many conflicts associated with land use for quarrying and the need for long-term planning is a pressing social, economic and political issue” (Glavind, 2009, p.129). Therefore there is a need to reduce surplus materials and focus on no-waste production in the aggregate industry. The energy consumption for the production of aggregate is quite small compared with that of Portland cement. “Energy to produce coarse and fine aggregates from crushed rock is estimated by the Portland Cement Association’s Life Cycle Inventory to be 35,440 kJ per ton (35.44 MJ per ton). The energy to produce coarse and fine aggregate from uncrushed rock is 21,190 kJ per ton (21.2 MJ per ton)” (Calkins, 2009, p.109). The greater concern with regard to aggregates is the energy consumption for transporting aggregates from the quarry to processing and then on to the customer as they are heavy and bulky materials. The sustainable answer to this is to use local aggregates to reduce the impact of transportation on the environment. “Because aggregates are so heavy, they are usually obtained within 100 miles of a ready mix plant, often even closer” (Calkins, 2009, p.112). Obtaining local aggregates will likely have the largest impact on reducing transportation energy use and emissions. For buildings in Oklahoma, the use of fine and course aggregates that are sourced locally causes the concrete to take on the red hues of the surrounding soil which allows the building to blend in beautifully with the surrounding landscape.

Reclamation of quarries is increasing as a way to restore habitat and a more natural landscape to the mined area. "Reclamation may be implemented following four reclamation strategies: progressive, segmental, interim, or post-mining" (Langer, 2009, p.4). Progressive reclamation immediately follows the removal of aggregate. This strategy is impractical for operations that blend mined material from different areas of the quarry. Segmental reclamation follows the removal of minerals in designated sections of the mine and is the most cost-effective strategy in homogeneous mines. Interim reclamation temporarily stabilizes disturbed areas with fast-growing grasses and later implements the final reclamation plan. Post-mining reclamation does not begin until the entire mine has been exhausted, which may lead to further deterioration of the quarry and result in longer regeneration times. Reclamation can produce economic benefits by reusing pits or quarries as residential property, industrial and commercial properties, golf courses, recreational areas, and botanical gardens. "Some reclamation uses an artistic approach where the site is celebrated as a work of beauty and unique experiences" (Langer, 2009, p.4). Quarry Grove, on the Oregon coast, is a quarry that was converted into a man-made tidal zone nourished by wave action. "The site was designed as an educational tool where visitors can view nature taking its course as marine life invades the area" (Langer, 2009, p.5). A mined-out sand and gravel pit along the South Platte River in Littleton, Colorado was reclaimed as a natural wildlife area. "The design made use of native seed mixes, and incorporated trails, fishing along the river, and educational tours at a nature center" (Langer, 2009, p.6). The South Platte Park is one of the largest wildlife parks within city limits in the United States. "Sustainable Aggregate Resource Management (SARM) has tremendous potential to improve quality of life. In today's expanding suburban areas, recently mined-out aggregate pits and quarries, as well as abandoned sites, are routinely converted to beneficial second uses; often these uses replicate natural conditions and create biodiversity" (Langer, 2009, p.15).

Where possible, the use of recycled or reclaimed aggregate should be employed to lower the need for mining virgin aggregates. Demolition of roads and buildings generates large quantities of waste. Previously, most of this waste was disposed of in landfills. "Today, concrete is commonly recycled" (Langer, 2009, p.12). The largest collection of research on the use of recycled aggregates from hardened concrete has been gathered under the research of RILEM (The International Union of Laboratories and Experts in Construction Materials, Systems and Structures) through a series of symposiums, the

proceedings from which have been published in a book about the subject. “Due to environmental considerations and the high cost of waste disposal, most countries in Europe have established short-term goals aimed at recycling 50 – 90% of the available construction and demolition waste (Mehta, 2001, p.63). Although countries in Europe have implemented standards regarding the use and application of recycled aggregate, no such standards exist in the United States. The state of the art of recycling concrete and masonry demolition debris in the U.S. is advancing, although slowly. “At the present time there are no U.S. national standards and few specifications that deal specifically with the subject of recycling these materials” (Kibert, 1994, p.83).

There are two key technical issues associated with the use of recycled aggregate in the production of new concrete. “The first is that recycled aggregate holds significantly more water, 5 – 8% compared to 1.5 – 3% for virgin materials. The problem can be solved by using blends of recycled and natural aggregate or by using water-reducing fly ash in concrete” (Mehta, 2001, p.63). The second issue is that “recycled aggregate performs slightly lower than virgin aggregates when it comes to compressive and flexural strength – 80 – 100% comparatively” (Kibert, 1994 p.86).

One of the benefits, besides environmental impacts, that recycled aggregate boasts is that “under freeze-thaw conditions, testing has indicated that recycled aggregates are superior in durability to their virgin counterparts” (Kibert, 1994, p.87). In general recycled aggregate concrete has good workability, durability, and resistance to freeze-thaw action. In the U.S., most of the recommendations that exist are based strongly on the RILEM specifications published in 1994. Recycled aggregates for use in new concrete structures are broken down into three types. “Type I is primarily produced from masonry rubble such as concrete blocks and bricks. Type II is produced from concrete rubble from structures that are cast in place. Type III is a mixture of the two former types with a minimum of 80% natural aggregates, a maximum of 10% of Type I and the remaining percentage made up of Type II” (Glavind, 2009, p.130). When recycled aggregates are specified in a building project that consists of Type III, where only 20% of the virgin aggregates are substituted with recycled aggregates, it is assumed that the structural properties are equal to concrete made solely of virgin materials. Use of Type III will therefore negate the need for testing of the concrete before it is approved for use in a specific building.

Another solution for the reduced performance of concretes with more than 20% recycled aggregate content is the use of fly ash as a substitute for Portland cement. The use of fly ash as partial replacement of Portland cement leads to significant improvements in strength and can mitigate the effect of reduced performance from recycled aggregates. “At 168 days mixes containing recycled coarse aggregate and recycled fine aggregate where 30% of the cement is replaced by fly ash were 30% stronger than concrete made with all virgin materials” (Wainright, 1994, p.329). Additional fly ash content up to 50% is acceptable, but a slight reduction in strength back to that of pure Portland cement concrete is observed. Therefore, a 20% substitution of recycled aggregate, along with a 50 – 70% fly ash substitution for Portland cement is the optimal recipe. “The use of recycled aggregates is desirable from both economic and environmental standpoints” (Kibert, 1994, p.87). Diverting as much waste as possible away from landfills is the right thing to do and when recycled aggregate can perform as well as virgin aggregate, it should be used. This reduces the need to quarry virgin aggregate and helps to reduce the amount of habitat alteration and other problems related to mining activities.

The energy consumed in the mining, crushing and transportation of virgin aggregate and sand is the fuel required to power heavy equipment used in the process. In addition, the energy consumed in the crushing and processing of construction demolition waste into recycled aggregate for new concrete is considered to be the same. The Portland Cement Association’s figures from above are conservative with regard to the embodied energy of aggregates and sand. They take into account the production process, but neglect the mining process. “Generally, aggregate and sand for use in concrete is mined locally and therefore long-distance haulage is uncommon. The embodied energy in the mining, processing and short-range transportation of sand is 0.1 MJ per kilogram” (Langer, 2009, p.10). This translates to 41,700 BTUs (44 MJ) per ton of sand. “The embodied energy for the mining, processing, crushing and short-range transportation of coarse aggregate is .03 MJ per kilogram” (Langer, 2009, p.10). This equates to 125,000 BTUs (132 MJ) per ton of coarse aggregate. Considering the typical mix of concrete contains 40% coarse aggregate, the contribution of embodied energy to the final concrete mix is 50,000 BTUs (52.75 MJ) per ton of mixed concrete. Sand or fine aggregates constitutes an average of 30% of the concrete mixture and therefore contributes 12,510 BTUs (13.2 MJ) to the embodied energy of one ton of concrete.

4.2.4 Water

Even though fresh water is abundantly available in most parts of the world, it is being used freely for all purposes by the concrete industry. Construction codes routinely recommend the use of potable water for concrete mixing and curing. The situation is changing as fresh, clean water is becoming scarcer on a rapidly increasing scale. Although Earth is a water planet, less than 3% of that water is fresh and most of it is locked up in glaciers and ice caps. Growing agricultural, urban and industrial needs are reducing water tables on every continent and the need to use this resource more efficiently is coming to light. The concrete industry is one of the largest consumers of fresh water and it is imperative that they begin to use this resource more efficiently. "In addition to approximately 20 gallons per cubic yard of wash-water used by the ready mix concrete trucks, we're using too much water for concrete mixing. The yearly global mixing water requirement of 2.64 billion gallons (1 trillion liters) can be cut in half by better aggregate grading and by greatly expanding the use of mineral admixtures (such as fly ash)" (Mehta, 2001, p.64). In addition, there is no reason why the industry should be using municipal drinking water for mixing concrete. "Water used in making concrete should be clear and free of sulfates, acids, alkalis, and humus" (Spence, 2011, p.115). However, Mehta (2001) points out that most recycled industrial waters or even brackish natural waters are suitable for making concrete, unless proven otherwise by testing (p.64). Water of questionable quality can be used for concrete if test mortar cubes have seven-day and twenty-eight-day strengths equal to 90% of the strength of samples made with drinkable water. The use of recycled water is completely acceptable as wash-water and does not need to be pure as its function is solely for cleaning mixing equipment. The substitution of fly ash for Portland cement, as previously discussed, will also significantly reduce the water needed for mixing concrete.

With regard to embodied energy, water as it is considered, is "free." Water generally constitutes 15% of the concrete mixture. Less is required with the use of fly ash as a substitute for Portland cement as previously noted. Although the impacts and implications of using fresh water are discussed in this section, water itself does not add to the embodied energy of the concrete mix.

4.2.5 The Manufacturing of Concrete

The energy from manufacturing concrete is not a crucial amount. For concrete production, the most relevant sustainability issues stem from recovered aggregate washed out from concrete, the reuse of wash water as mixing water and recycled aggregate from concrete and demolition waste. “The technology for reusing water in concrete production is well known and is being widely used already” (Glavind, 2009, p.132). The technology for recovering aggregates from fresh concrete is straightforward as crushing it and using it in a new batch is possible. However, the preferred way to dispose of rejected concrete is to let it harden and crush it for road-building purposes. This crushed concrete is used in place of gravel on the road bed. This is considered “down-cycling” rather than recycling a material and results in the eventual landfilling of the material once the road is slated for replacement. The crushing and re-use of rejected concrete as aggregate in new concrete is a preferred no-waste method of handling the solid waste generated by the ready mix plant.

The production of concrete requires energy as with all other building materials. At the concrete plant, electricity and fuel are needed for mixers, conveyors, pumps, trucks and other equipment. The contribution from the concrete plant to the carbon dioxide footprint of concrete structures is minor compared with that of cement production. Energy use and emissions from a ready mix plant vary by cement type and the addition of fly ash or other constituents. Mixes with lower cement content and higher fly ash content have lower embodied energy and consequently lower emissions. A Life-cycle Inventory by the Portland Cement Association of three different ready mixes supports this idea. One of the mixes studied was a standard 28-day compressive strength, 3000 psi ready mix using 100% Portland cement. The second mix replaced 25% of the cement with fly ash and the third replaced 50%. “The embodied energy for the standard Portland cement mix is highest at 1.13 GJ per cubic meter of concrete and was lowest for the 50% fly ash cement mix at 0.73 GJ per cubic meter” (Calkins, 2009, p.110). Carbon dioxide emissions are also reduced for the fly ash mixes. “The highest was for the 100% Portland cement mix at 211 kg per cubic meter and lowest for the 50% fly ash mix at 112 kg per cubic meter of produced concrete” (Calkins, 2009, p.110). “It is estimated that the production of one cubic meter of ready-mix concrete requires about 100 MJ of energy” (Glavind, 2009, p.133). This translates to 61,295 BTUs (64.67 MJ) per ton of concrete.

4.2.6 Construction

Environmental impacts during construction are usually not significant compared with the contributions from the other life cycle phases. Of significant concern for sustainability during construction is the use of concrete formwork. “Concrete formwork can use substantial resources if it is used once then torn off and discarded” (Calkins, 2009, p. 128). Formwork made of steel and plastic can be reused an infinite number of times. Wood can also be reused if form-release agents (sprayed on formwork to prevent the concrete from adhering to the formwork) that don’t damage the wood are used, such as plant-derived oils instead of petroleum-based oils. In addition, “wood formwork from a reclaimed source will also save resources” (Calkins, 2009, p.128). “Stay-in-place forms made of polystyrene that act both as formwork during construction and as insulation for the finished building are gaining popularity” (Demkin, 1998, MAT 03100 p.19). Formwork is one of the most expensive parts of building a site-cast concrete structure. “Formwork for both site-cast and precast products can be recycled and pose a significant potential savings in waste as the American Plywood Association reports that construction of concrete forms is the third greatest use of plywood” (Demkin, 1998, MAT 03100 p.19).

The use of concrete as a construction material results in minimal construction waste because, unlike sheet goods or dimensional lumber, “concrete is used on an as-needed basis so that little product is wasted” (Demkin, 1998, MAT 03100 p.22). Solid waste in the form of leftover concrete at the construction site is another concern. Most contractors will order at least as much concrete from vendors as they think they need to ensure uninterrupted completion of daily placement activities. “Returning excess material to the vendor for remixing with batches from later in the day can reduce the amount of solid waste from construction” (Demkin, 1998, MAT 03100 p.19). Concrete left in the truck is usually recycled at the ready-mix plant and so the waste from the use of concrete is rapidly disappearing.

There is another process that has not attracted much attention but which can result in non-negligible contributions to energy consumption. In some parts of the country and world with humid climates, the drying of concrete can cost energy” (Glavind, 2009, p.135). Very often each cubic yard of concrete has a surplus water content of 8 gallons which needs to be dried out before the finishing work can be completed. During the winter period in

particular, the drying of concrete involves large amounts of energy consumption, between 20 and 50 kWh per square meter of floor area depending on the conditions at the building site. Furthermore, expenses for heating and dehumidifying equipment are added to the energy costs. Oklahoma is a particularly humid environment during the summer months. To minimize issues with humidity, it is recommended that concrete be placed during less humid months allowing hydration to occur naturally without the use of energy-consuming equipment.

Energy consumption during the construction phase of a building project varies widely depending upon size, location and design. The energy consumed on a construction site is generally in the fuel consumed by heavy equipment used in the mixing and placing of concrete and is similar to that of the transportation of concrete to the job site. "It is estimated that 158 BTUs (0.17 MJ) per ton of cast concrete is used during construction" (Demkin, 1998, MAT 03100 p.20).

4.2.7 Use

Most of the environmental studies performed in the past have focused on materials and construction, but have neglected the operation and service phase of a structure. This phase is crucial because it constitutes the largest contribution to the total life cycle environmental impact. Furthermore, "this phase is where concrete can be used to solve environmental problems and minimize environmental impact" (Glavind, 2009, p.135). It is critical to consider this phase of a building's life in order to optimize a concrete structure mainly because a solution that appears green from a materials standpoint may prove to be a not-so-green solution when the post-construction phase is taken into consideration. "A very green material can result in a not-so-green construction if the durability is worse when compared with a traditional material" (Glavind, 2009, p.135).

The operation of buildings is the single highest contributor to carbon dioxide emissions in the world. This is generally found in the form of energy produced for heating, cooling and lighting as well as the energy required for maintenance and up-keep. "The energy use for heating and cooling a building accounts for 40% of the total energy consumption" (Glavind, 2009, p.136). In many countries, the energy performance of buildings is regulated by authorities or building codes. However, rapidly increasing energy prices are stimulating further improvement in efficiency on a voluntary basis. Concrete has

a beneficial effect on the energy performance and thermal comfort of a building due to its high thermal mass.

The effect that thermal storage has on the building depends on the heat capacity of the material – that which contributes to the heat exchange between the structure and the indoor air during temperature cycles. One condition that is needed for this to happen is that the concrete surface must be exposed; otherwise the storage effect drops dramatically. Floor coverings such as tile, carpet and hardwood will block this exchange because they provide too much insulation between the concrete mass and the surrounding air. “Normal weight concrete has the largest heat accumulation capacity and the effect is almost proportional to the density of the material” (Glavind, 2009, p.136). Because of the high heat capacity of concrete, heat will penetrate quite deep into concrete slabs, walls and roofs. Therefore, a significant percentage of the material can be utilized for heat storage compared with materials with a lower heat capacity such as wood or drywall.

Buildings that are passive in nature and utilize passive solar collection, natural ventilation and small fans to transport heat to and from the concrete mass, result in a reduction in heating and cooling energy consumption of 75% or more. In addition to reducing active energy consumption during the life cycle of the building, the use of concrete in structures contributes to durability and strength. Building owners find it invaluable to obtain a design with minimum maintenance requirements. Maintenance, repair and remodeling are often difficult to carry out and inevitably the users of the building will be disturbed during the process of repair. A significant reduction of carbon dioxide emissions can be achieved by the reduction (if not the elimination) of the need to replace and repair a structure with new materials.

Improving concrete durability is a long-range solution and a major breakthrough for improving the resource productivity of the concrete industry. Currently most concrete structures are designed for a service life of about 50 years. If most structural concrete elements are built to last for 500 years, the productivity of the concrete industry will increase by a factor of 10. Some concrete structures in this country begin to deteriorate in a matter of 20 years or less, and yet buildings and seawalls made of unreinforced Roman concrete continue to be in good condition after almost 2000 years. The reason behind this is the Portland cement concrete mixtures that are currently in use. Because of their early strength,

which aids in the speed of construction, Portland cement structures are highly crack-prone and become permeable during service. “Today’s construction practice, driven by a culture of ever-accelerating construction speeds, uses concrete containing a relatively large amount of high-early strength Portland cement” (Mehta, 2001, p.64). Roman cement which is a mixture of hydrated lime and volcanic ash (similar in properties to fly ash) produced a homogeneous product that set and hardened slowly but was more thermodynamically stable resulting in a very durable structure. If durability and sustainability are the goals of the future, construction practice must shift to achieve crack-free concrete structures in lieu of speedy construction schedules. In fact, “technology is available in the form of slower-hardening blended Portland cements containing 50 to 70% fly ash” (Mehta, 2001, p.64). The high-volume fly ash concrete provides a model for the future for making concrete that shrinks less, cracks less, and will be far more durable and resource-efficient than conventional Portland cement concrete. “The life cycle of high-performance high fly ash content concrete is much longer than that of usual concrete, and it can be recycled two to three times before it is transformed into road base aggregate” (Calkins, 2009, p.113).

4.2.8 Demolition and Recycling

When a structure reaches the end of its service life, it is common practice to demolish it to make way for new construction. The annual production of construction and demolition waste is enormous and continues to rise annually. “Waste concrete from demolition is the single largest category of construction/demolition waste and a significant part of the waste stream in the United States” (Demkin, 1998, MAT 03100 p.20). “Construction and demolition waste, especially from concrete buildings and structures, is highly recyclable when it is sorted and crushed down to usable fractions” (Glavind, 2009, p.138). Although this is a huge step in reducing waste, demolition and crushing requires energy and leads to carbon dioxide emissions. Therefore, the transportation distance between the demolition site and the site of reuse should be kept to a minimum. Because of its weight and bulk, demolition debris is similar to aggregate in terms of the environmental cost of transporting it over longer distances. Recycling crushed concrete back into concrete production has been shown to be effective during the earlier discussion on aggregates.

Another aspect of concrete which is often ignored is its ability to sequester carbon dioxide over time. “During the service life of a concrete structure the carbonation process in

concrete is generally slow” (Glavind, 2009, p.139). Also, in many cases, concrete is covered; it is used in protected environments indoors; or used as foundations and are subsequently covered by soil. So the amount of carbon dioxide that is absorbed by concrete during its service life is typically low. “Over several years, 100 pounds of Portland cement (as a component of concrete) may absorb as much as 30 pounds of carbon dioxide” (Demkin, 1998, MAT 03100 p.15). The reason for the slow absorption is that only the surface of the concrete is in contact with the air and not its full bulk. However, “when a concrete structure is demolished and crushed, the specific surface area of the concrete is multiplied significantly and the carbonation rate accelerates proportionally” (Glavind, 2009, p.139). This is an effect that has been traditionally overlooked, but is starting to gain some attention. In a full life cycle analysis of a concrete building from the manufacture of the Portland cement up to and including demolition and crushing of the hardened concrete, carbon dioxide emission has been overestimated if the uptake during service and at demolition is not included in the calculation. “A study performed in North America by Gajda and Miller (2000) shows that concrete through its life cycle carbonated 28 – 39% during its service life. Taking into account secondary life involving crushing of the demolished concrete, the percentage of carbonated concrete in a 100 year life cycle increased to 86%” (Glavind, 2009, p.139). As an average, between 33 and 57% of the carbon dioxide emitted from cement production will have been taking up during a 100 year life cycle that ends in the crushing of the demolished concrete and its possible reuse as aggregate in fresh concrete. This is a complete cradle to cradle approach to concrete sustainability.

An economic benefit of recycling concrete is the value of the steel reinforcing that is removed during the process. When demolition waste is landfilled, the steel is not usually removed from the concrete. However, “when concrete is recycled, removed steel can be sold for scrap, bringing additional economic value to recycling efforts” (Calkins, 2009, p.124). Considering the majority of steel produced today is derived from recycled scrap, this diverts usable steel from the waste stream and puts it to work in new steel applications.

According to the Materials Resource Guide published by the American Institute of Architects, “currently there is no information on the amount of energy consumed in the reuse, recycling, and disposal of concrete” (Demkin, 1998, MAT 03100 p.21).

4.2.10 Conclusion

Much work has been done to document and improve the sustainability of concrete, but the effort must continue due to the challenges that the concrete industry faces. “The use of concrete is increasing tremendously, so small gains in sustainability can be offset by increased use. Strides in production efficiency, recycling, and design – coupled with the traditional benefits of strength, longevity, and thermal mass – make concrete a front-runner among environmentally friendly building materials” (Demkin, 1998, MAT 03100 p.19). It is time to shift attention from the immediate sustainability of a material to a full life cycle analysis of the material in the building from resource extraction through demolition. When assessing environmental performance of a concrete structure, the entire life must be considered. This includes the environmental impact associated with the production of the various constituent materials, construction of the structure, use, maintenance, demolition and finally recycling of the demolished materials. The industry must change from a mentality of attempting to solve a single problem, i.e. carbon dioxide emissions from cement production, to an approach that encompasses the entire life cycle of the material. This is especially the case regarding energy, where attention in the future needs to focus on the exploitation of the excellent thermal capacity of concrete to save and possibly eliminate energy usage during occupancy. Concrete structures will help to reduce and in some cases eliminate energy needed for cooling and heating and at the same time ensure a comfortable and even indoor climate. Further research on the recycling of concrete is needed to optimize its post-service uses. In addition, further documentation on carbon dioxide emission and uptake is needed to assess the life cycle of concrete with regard to greenhouse gas emissions. An approach that includes the manufacture, use and life-cycle of concrete needs to be used to address the fact that selection of concrete as a building material is indeed green.

4.3 Glass

Glass performs numerous different tasks in building applications. The most important of these are “allowing daylight into the interior of a building, enabling views into and out of a building and at the same time providing protection against the weather” (Weller, 2009, p.33). Many materials have been used over the centuries as cladding materials – a skin as it were – to cover a building and protect its interior from the outside environment. “A

façade is defined in the Oxford dictionary as ‘the face of a building’” (Elkadi, 2006, p.1). A façade both obscures and protects a building’s contents and core. Openings and windows, referred to as fenestrations, give the façade its character and distinction. “Windows actually preceded the development of glass by several centuries; they were part of an architectural aesthetic of buildings during the Fourth Dynasty in Egypt. An example of this can be seen in the openings of the pyramid of Dahshur (2723 B.C.). More elaborate windows were found in the temple of Ramses II in Medinet Habu (1198 B.C.) and in the Hypostyle Hall in Karnak (1198 B.C.)” (Elkadi, 2006, p.2). These windows or openings were not only used to provide lighting and ventilation to the interior, but also as a deliberate playing with light and shadows to accentuate possessions and spaces within the temples. “Flat glass has been used to enclose space for nearly two millennia and is one of the oldest manmade building materials” (Wurm, 2007, p.10). At the same time, continuous improvements in the manufacturing and refining process makes glass one of the most modern building materials in use today. “Almost any task associated with a modern building skin could be fulfilled with the help of this material. This makes it possible to overcome the contradiction between the fundamental need for shelter from the elements and the simultaneous desire for openness to light, paving the way for building structures that provide shelter without entombing the dweller” (Wurm, 2007, p.10). Glass surfaces bring in views, light and solar warmth. Like the rest of the wall, glass must protect the inhabitants against rain, cold, heat and noise. Few materials can satisfy these demands at the same time. “There have been many alternatives through history: shell, horn, parchment, alabaster, oiled textiles, crystalline, gypsum and thin sheets of marble” (Berge, 2000, p.100). None of these seriously rival glass in its ability to be totally transparent to views and to allow as much light in as possible.

“Glass is arguably the most remarkable material ever discovered by man. Made from the melting and cooling of the Earth’s most abundant mineral, it provides a substance that is transparent and rock hard, so chemically inert that almost anything can be kept in a container made from it” (Wigginton, 1996, p.6). Glass is a solid, super-cooled, liquid ceramic material. Its characteristics include transparency, brittleness, hardness and chemical inertness. Glass is highly prized for its ability to keep weather out of interior spaces while allowing light to enter. For these reasons, glass has a variety of architectural applications.

Glass is a material that has been in use for many thousands of years. As early as 6000 or 5000 B.C., the Egyptians were making glass jewelry of fine workmanship and beauty. “Decorative glass rods from Babylon and glass beads from Egypt are among the oldest existing glass artifacts, dating from around 2600 to 2500 B.C.” (Demkin, 1998, MAT 08810 p.1). More than any civilization the Roman Empire made extensive use of glass. “Notably, the Romans were the first to use glass for windows, probably in Pompeii before the birth of Christ” (Demkin, 1998, MAT 08810 op.1). This is because the basic manufacturing process is relatively simple. A naturally occurring raw material is heated, and then formed into the desired shape. With the addition of minor elements during the process, different properties can be obtained.

In the 1950s, an ingenious method of making relatively inexpensive flat glass of high quality was developed in England by Alistair Pilkington of the Pilkington Glass Company. “In the float process, a single strip of glass from the melting furnaces floats into the surface of molten tin at a carefully controlled temperature” (Amstock, 1997, p.39). Floating the molten glass ribbon onto a molten metal rather than a rigid bed would result in a sheet where both sides were flat, smooth and finished (Wigginton, 1996, p.64). This method was introduced into the United States in the early 1960s and quickly overtook all other types of glass manufacturing for architectural applications. “As Alastair Pilkington said, ‘Because the surface of the metal is dead flat, the glass is dead flat too. Natural forces of weight and surface tension bring it to an absolutely uniform thickness.’” (Wigginton, 1996, p.64).

“In 1963 float glass was introduced into the construction field, where it continues to be the industry standard today” (Demkin, 1998, MAT 08810 p.2). The high dimensional accuracy and geometrical precision of float glass “make it the only glass considered suitable for use in buildings if it has to be further processed” (Wurm, 2007, p.48). Therefore, float glass comprises approximately 98% of the flat glass currently manufactured in the United States. The product portfolio of float glass is small but nothing can compete with its high optical quality. Therefore, “float glass is the basic glass for all processing stages and is used in all areas of the building” skin (Wurm, 2007, p.48). Advancements and improvements in the process continue to be made.

“Glass, the unnatural material, is accepted more and more as a key component in the sustainable development of facades and in improving the ecological performance of

buildings” (Elkadi, 2006, p.26). More and more, facades are seen as an interface zone in which players interact and influence each other. It is now a transitional space where people indoors experience something of what the outdoors is like and consequently where people outside get a glimpse of the functions within.

Glass is composed of three primary raw materials: glass sand, limestone and soda ash. Other materials that can be included in the mixture include cullet (shards of glass recycled from broken or rejected pieces and from glass recycled from existing buildings and demolition), salt cake (which is added to aid in furnace cleanliness), and other trace amounts of oxides that assist in increasing material durability. These oxides and additives are usually part of a proprietary recipe so only the basic ingredients will be analyzed. “As with most products, the composition of glass is carefully controlled, typically by purchasing relatively pure raw materials and mixing them carefully before production” (Atkins, 2009, p.171).

4.3.1 Glass Sand

Glass sand is the major component in the manufacturing of glass for use in buildings. It constitutes 60% of the raw mixture that is added to the furnace for melting and makes up 70% of the weight of the final flat glass product. In this matter “glass has a distinct advantage over other manufactured materials, in that its manufacture uses one of the most abundant materials on the surface of the planet” (Atkins, 2009, p.172). To be used in glass production, glass sand must be pure quartz or silica (the oxidized form of silicon). “U.S. consumption is met largely by domestic glass sand deposits in New Jersey, the Allegheny Mountains, and a portion of the Mississippi Valley” (Demkin, 1998, MAT 08810 p.8). Therefore, the location of glass plants is often determined by the location of these deposits. Trace elements of iron oxide and chromium are generally present in the final product which is evident at the edges of a plate of glass in the form of a green hue. “Completely removing these trace amounts would take more time and energy than is deemed necessary for producing quality glass. In addition, fine grain sand is preferable, because processing of smaller particles requires lower temperatures and, therefore, less energy” (Demkin, 1998, MAT 08810 p.8).

The primary method for mining glass sand is in open pit mines. Various types of machinery are used to excavate the sand and then further crush, separate and screen the

various particles. Excavation generally occurs by means of power shovels, dragline cranes, front-end loaders and conveyors. "Most open-pit mining operations include site clearing and overburden removal; mining of silica rock or sand; material processing such as crushing, screening and classification; and reclamation of the extraction area" (Demkin, 1998, MAT 08810 p.8). Upon extraction the sand is transported via suction pump, earth mover, barge or truck to nearby processing plants.

Although extraction of the sand is not a process that is extensively energy intense, there are negative aspects to sand mining that include waste water, land disturbance and fuel consumption. Open pit excavation disturbs the land in a manner which increases soil erosion up to ten times greater than mechanized farming and up to four times worse than timber harvest. In addition, processing glass sand requires large amounts of water which when discharged contains suspended clay particles that increases the turbidity of streams and lakes. Both soil erosion and waste water issues are effects of mining that can be remediated or prevented with careful attention. In general the effects of land disturbance from mining glass sand can be mitigated to a great extent by careful restoration management. "Restored lands from mining almost always have different vegetation patterns as a result of changes in topsoil porosity and chemistry" (Demkin, 1998, MAT 08810 p.8). In general, resource depletion is not of concern due to an abundant supply of glass sand in the United States.

The energy consumed in glass sand mining is mainly in the form of fuels used to power heavy equipment. Estimates of energy use for mining, crushing, screening, and classifying vary with the process used. "In general, 430,000 BTUs (454 MJ) are expended for mining and processing one ton of sand" (Demkin, 1998, MAT 08810 p.9). An estimated 270,000 BTUs (285 MJ) are required to mine and process the 1,184 pounds of glass sand required to produce one ton of finished glass.

4.3.2 Soda Ash

Soda ash provides the sodium carbonate needed to lower the melting temperature of the glass sand mixture. Soda ash is primarily mined by way of trona deposits in the Earth, though it can be produced synthetically. "Currently 90% of the soda ash used in glass production is obtained using trona mining which can be mined using two different methods. About 1.8 tons of trona is required to produce one ton of soda ash" (Demkin, 1998, MAT

08810 p.11). The first of steps of trona mining requires basic underground mining procedures including undercutting, drilling, blasting and crushing. Once mined, it is transported to the surface for further processing. Once at the surface, trona is calcined into crude sodium in a gas-fired rotary kiln. It is then purified, crystalized and dried. A second and more efficient method of soda mining is achieved through solution mining. This involves dissolving the deposits into dilute aqueous liquor that is then pumped from the mine and converted to sodium carbonate via a treating process that involves a lime calcining procedure. Both methods take approximately 1.8 tons of trona to produce one ton of soda ash.

Environmentally, the impacts of soda ash mining are similar to glass sand mining. One distinct difference is in the calcining process that increases all types of emissions, including carbon dioxide. In addition, waste water is a considerable factor in the process of soda ash mining and processing and it is treated in evaporation ponds which can be harmful to migratory waterfowl.

Energy consumed during trona mining and soda ash production comes primarily in the form of fuels consumed to power heavy equipment. In addition, the production of soda ash is energy intensive. "Since 1973, energy requirements for soda ash production have been reduced by replacing gas-fired dryers with steam-tube units and installing mechanical vapor recompression units to replace triple-effect evaporators" (Demkin, 1998, MAT 08810 p.13). "An estimated 8.59 million BTUs (9,071 MJ) are required to produce one ton of natural soda ash" (Demkin, 1998, MAT 08810 p.13). This translates to an estimated 1.62 billion BTUs (1,711 MJ) consumed in the mining and processing of the 394 pounds of natural soda ash required to produce one ton of glass.

4.3.3 Limestone

Limestone is the major source of lime for glassmaking. It provides the lime needed to stabilize the soda and silica mixture to make it non-soluble in water. Lime makes up the smallest percentage of the components needed for the glass mixture and requires no special equipment. Most limestone is quarried from open pits and is calcined to break the limestone down into calcium oxide. As with cement production, this results in the release of carbon dioxide at the same rates that it does for the production of cement. In addition, the

same environmental effects of limestone mining for cement production are also felt with regard to glassmaking.

Estimates of energy use for materials acquisition steps such as mining and crushing vary with the processes used. "In general, the energy required for limestone mining and processing is estimated at 164,000 BTUs (173 MJ) per ton" (Demkin, 1998, MAT 08810 p.11). This translates to 30,000 BTUs (31.6 MJ) required to mine, process and transport the 363 pounds of limestone needed to produce one ton of glass.

4.3.4 Manufacturing of Glass

Once the raw materials of glass sand, soda ash and lime arrive at the float glass manufacturing facility, the most energy-intensive part of the process begins. The raw materials are stored in silos at the plant until they are needed. "Through a computerized process, the exact amount of raw material from each silo is put on the scales until the batch makeup is completed" (Amstock, 1997, p.41). The materials must be thoroughly mixed to form a homogeneous material before a wetting agent is added. Once the mixture is complete, it is "dropped into the feeder where it is placed into a furnace along with cullet (scrap glass) which is used as a raw material to increase production yields and reduce air emissions" (Demkin, 1998, MAT 08810 p.13). Cullet improves the melting characteristics of the mix and decreases the energy needed for melting as it is already a finished glass material with a lower melting point than the individual raw materials. A typical plant will reject or lose around 10% of its output which is recycled as domestic cullet. "Cullet from external sources is known as foreign cullet" (Atkins, 2009, p.172). The exact composition will not be known with foreign cullet, however because the basic ingredients are common to most manufacturers, the use of cullet of the same color should not pose a problem in the manufacturing of new glass.

In the float glass method, the melting furnace (known as a continuous regenerative furnace), powered by natural gas, is running continuously. "A typical furnace, 175 feet long, 30 feet wide and four feet deep, holds in excess of 1600 tons of molten glass" (Amstock, 1997, p.42). The fuel used is usually natural gas, often with electric boosting to keep temperatures steady during the process. These furnaces typically produce an average of 500 tons of glass per day running non-stop around the clock. The float process has its disadvantages. As originally conceived, it had to run twenty-four hours a day, seven days a

week throughout the year. “Stopping it implies the solidifying of the tin and the seizing up of the plant” (Wigginton, 1996, p.64). Another disadvantage is the time it takes to vary the content of the mix to produce glasses of different colors. “It can take several days’ worth of ribbon production to produce a glass of consistent color. The only alternative is to have a dedicated float line for each color, which places great demands on production programs in terms of predicting the market for each color” (Wigginton, 1996, p.65).

Once the materials reach the furnace, they are heated to 2900 degrees Fahrenheit and mixed uniformly. The material is then passed into the float chamber as it spreads to a wide ribbon and cools to 1900 degrees Fahrenheit, which causes the mixture to have a toffee-like consistency. “The float bath is a chamber whereupon the molten glass floats on top of molten tin. The tin bath holds approximately 150 tons of molten tin (a value of \$1.5 million) and is 2 to 3 inches deep” (Amstock, 1997, p.42). The temperature in the float chamber is controlled to keep the tin float bath melted without adding to the heat of the glass. The thickness of the glass is controlled during this process by adjusting the depth of the side barriers in the float bath. “Thicknesses of float glass range from 3/32 to ½ inch (2.5 to 12mm)” (Spence, 2011, p.544). The controlled heating during this process melts out all irregularities, which is the primary reason why the resulting glass sheet has parallel surfaces that do not require grinding or polishing. To ensure the bottom surfaces are not damaged in the annealing process that follows, the glass is allowed to cool while still on the molten tin until it is solid enough to be handled by mechanical rollers without being damaged.

The next stage in glass production is the annealing process, which consists of two operations. “When entering the annealing chamber, the glass is held above a critical temperature long enough to reduce internal strain by plastic flow to less than a predetermined maximum, and the second cools the mass to room temperature slowly enough to hold the strain below this maximum” (Demkin, 1998, MAT 08810 pp.15-16). “The temperature is slowly lowered, allowing all parts of the glass to cool uniformly” (Spence, 2011, p.546) which reduces the strain on the material and prevents thermal breakage. This process is accomplished in a chamber called an annealing lehr. The lehr is an automated continuous annealing machine that cools the glass sheet from 1100 degrees down to 200 degrees Fahrenheit in a controlled uniform manner. The process of cooling in the lehr occurs on a conveyor system that can span up to one-third of a mile.

Once the cooling is completed, the glass emerges as a continuous ribbon and must be inspected prior to the finishing process. Should any glass be identified as deficient or unsatisfactory, it is cut away from the strip, crushed, and returned to the beginning of the process as cullet.

The final stage in float glass production is the finishing process. This usually involves cleaning, cutting, enameling, grading and gauging; but can vary depending on the intended use of the glass. "The cutters score the glass with carbide wheels in an X (across) and Y (along) direction for a particular customer or production runs" (Amstock, 1997, p.44). Often, over a dozen size changes are typical in one day of production. Glass factories turn out a finished product that is a result of an intense manufacturing process. As it travels on its journey, glass becomes a raw material for the next step and is used to fabricate a variety of building materials, such as windows, doors, and skylights. The discussion of the manufacturing process of various glass products is beyond the scope of this report, therefore only the embodied energy of the glass itself will be taken into account. Regular float glass is made in three forms with specific qualities: silvering, which is used in selected high-quality pieces for optical uses and mirrors; mirror glazing for general-purpose mirrors; and glazing for door and window glazing (Spence p.544).

"The melting furnace contributes approximately 99% of the total emissions from a glass plant, both particulates and gaseous pollutants" (Demkin, 1998, MAT 08810 p.16). Proper maintenance and firing of the furnace can control most emissions, increase efficiency, and reduce operating costs. Particulate emissions are controlled with great efficiency by enclosing the equipment and installing bag-houses, filter vents, and exhaust systems. Significant energy is consumed in the glassmaking process, although estimates do vary. "The embodied energy of glass production is approximately 12 million BTUs (14,200 to 15,825 MJ) per ton. This breaks down into as much as 8 million BTUs (7,174 to 8,440 MJ) per ton of glass produced being expended in the melting process, another 4 million BTUs (4,220 MJ) per ton expended in the forming, annealing and finishing processes" (Demkin, 1998, MAT 08810 p.16), plus another 1 million BTUs in the processing of cullet and transportation of raw materials to the furnace. In total, including extraction of raw materials, processing and finishing, the embodied energy of finished sheet glass is approximately 15 million BTUs per ton.

Although the embodied energy of glass is high, there are benefits in glass manufacturing that assist in its sustainability as a construction material. All of the solid waste that is produced in the form of rejected glass is crushed and used again in the melting process which leads to 100% production recycling. In addition, glass is 100% recyclable and whenever possible, should be returned to glass manufacturers when it is replaced or demolished from buildings to be re-used in the manufacture of new glass sheets.

4.3.5 Construction

Between the formation of plate glass and the construction site, glass intended for architectural uses can undergo several transformations that assist it in becoming more energy efficient. Such processes include multiple glazing of windows, applications of films or inserts of gas between panes, placement into casements for windows, or other inserts for attachment to curtain walls and other building applications.

“On a practical human time scale, stresses are usually applied and results measured at a rate far too fast for the flow properties of glass at room temperature to show. Under these circumstances, common glass behaves like an elastic solid” (Amstock, 1997, p.127). However, glass, even cooled and installed in a building, is technically in a liquid state. The transparency of glass actually derives from its basic liquid structure. “It is common for liquids to be transparent, whereas transparency is relatively rare in solids” (Amstock, 1997, p.129). As light passes through a piece of glass, it encounters only two optical boundaries: the first one entering the glass and the second one leaving it – in other words, the exterior and interior surfaces of the glass. With this in mind it is not surprising that “a single sheet of ¼ inch thick clear float glass transmits 90% of the light and 89% of the heat energy that hits it” (Spence, 2011, p.554). The most desired glass for architectural projects involving direct-gain solar heating is double-glazed argon-filled panes of glass that transmit 82% of light and 71% of the heat that hits the outside surface of the glass.

“Single pane windows are now considered inadequate as a barrier between the indoor and outdoor environments. The R-value (insulation value) of a quarter inch thick pane of glass is somewhere between 0.8 and 1.0” (Demkin, 1998, MAT 08810 p.2). By comparison, the R-value of exterior wall insulation should be between 13 and 19. Double glazing (the use of two panes of glass with a half-inch air space between) can increase the R-value to between 1.5 and 1.8. In addition to double (and occasionally triple) glazing, the

application of a thin metallic coating can be applied to the inner surface of the exterior pane of glass which assists in blocking radiant heat from escaping, as well as reflecting produced interior heat back inside, which is known as low-E (low-emittance). Solar radiation (short-wave infra-red) hitting the outside of the glass is still admitted at the same percentages as other glazing and transformed into long-wave infra-red which is more commonly known as heat. The properties of low-E coatings are such that the transmission of solar radiation in the short wavelengths is high but drops off dramatically in the long wavelengths. "The net result is that solar radiation is allowed to enter a space but is prevented from re-radiating back through the glazing unit" (Spence, 2011, p.549). Further insulating properties can be achieved by filling the air space between double-glaze panes with argon. "Argon is inexpensive, non-toxic, non-reactive, clear and odorless" (Elkadi, 2006, p.81). "Because the insulation in multiple-glazed windows is the entrapped gas, increasing the gas space thickness increases the overall R-value" (Ernst, 1997, p.325). This means that a half-inch air space will insulate better than a quarter-inch air space. There is a law of diminishing returns past the half-inch space. "Beyond this thickness, inter-pane convection increases carrying heat from the inner to the outer pane through air circulation" (Ernst, 1997, p.325). Therefore air spaces beyond a half-inch do not result in an increased R-value. Filling the air space with argon primarily works because argon is less conductive than air. The R-value of a double-paned argon-filled window unit is 2.2, compared to 0.8 to 1.0 for standard clear single-pane units. With the addition of interior and exterior air films, the low-E coating and the introduction of argon between the panes, the R-value rises to 4.0. "Special coatings that allow for high solar gains into a room while minimizing conduction heat loss through the glazing are very effective in passive solar heating" (Athienitis, 2002, p.61). The preferred type of glass for use in passive solar applications is the low-E, double-glazed argon-filled windows and doors because they let in a large percentage of heat and light while reducing the loss out of heat at night.

Proper installation of glass is also a key to saving energy and reducing the impact on the environment. This includes appropriate sealing, operability, and solar orientation. Correct consideration of all these aspects is crucial in the design process to minimize heating and cooling of the building while increasing natural ventilation and daylight. Installation of glass into curtain wall systems or windows into buildings does not require specialized labor or machinery in most applications. Once installed, glass rarely requires

special maintenance aside from cleaning, opening and closing of operable panels, and replacement of cracked or broken panes.

The energy used in the construction and assembly of glass panels is negligible and does not contribute enough to the embodied energy of the building to be mentioned.

4.3.6 Use

“Historically, the prime performance characteristic of glass in relation to architecture has been in respect to the transmission of light” (Wigginton, 1996, p.70). The primary structural use of glass is as cladding, curtain walls or windows set into structural frames. “Typically, the structural requirements are to resist wind loading, dead load and accidental impacts” (Atkins, 2009, p.175). Aside from these properties, glass is a brittle material that in standard glazing and window applications cannot withstand structural loads and must therefore be encased within or between structural members, or placed outside of structural elements in the form of a curtain wall.

Glass is a material that, although it has a very low insulating value, can assist in conserving energy. “Its ability to transmit light into homes and offices greatly reduces the need for artificial lighting and the associated electrical energy production from fossil-fuel-fired utilities” (Demkin, 1998, MAT 08810 p.19). Wyckmans (2007) agrees that “appropriate admission and distribution of daylight in non-domestic buildings increases their potential for energy conservation and for providing a healthy and comfortable indoor environment” (p.85).

When taking indoor air quality into account, glass is inert and has virtually no adverse impacts. “Glass does not produce pollution while in use” (Berge, 2000, p.105). In laboratory test chambers, “there was no evidence of VOCs absorption into glass” (Demkin, 1998, MAT 08810 p.18), nor does glass off-gas any VOCs into the atmosphere. Since glass is not porous, it will not absorb moisture or chemical elements in the ground or atmosphere. “Glass used in typical applications in building construction is very durable and more resistant to corrosion than many other materials” (Spence, 2011, p.545). Fenestration which is the principle use of glass can significantly reduce the trapping of such pollutants such as VOCs and other indoor air pollutants when windows are designed to open and provide natural ventilation. Operable windows and natural ventilation significantly improve indoor air quality by facilitating frequent fresh air changes within the building.

Glass use in façades provides more than passive means at reducing heating, cooling and lighting loads within a building. The relationship with the outside world is also an important factor in the use of glass. In addition to the “subjective three-dimensional quality of a visual link with the outside” (Schuler p.139), glass also provides psychological comfort for building inhabitants. “The view through glass to the outside is regulated in Germany in DIN 5034 “Daylight in interiors” part 1, which deals with the psychological need for a person to have some reference to his or her surroundings” (Schuler, 2007, p.140). In Germany, it is not permitted to plan permanent spaces at work without a reference to external surroundings. By its property of transparency it opens up buildings to the outside world. This psychological effect is very valuable. “People may enjoy the view on the outside world and are not divided from it by a solid closed wall” (Njisse, 2003, p.83). Especially in the colder regions and seasons on this planet, it is an essential aspect. “Buildings can be kept comfortable much easier without having to give up the possibility of looking outside” (Njisse, 2003, p.83). The introduction of glass to the building façade has opened up buildings not only from the inside out, but from the outside in. “The visual borderline of what is in or outside the building becomes, on purpose, blurred” (Njisse, 2003,p.83). The ability to see sunlight and the sky is invaluable within a building and substantially increases the comfort of its occupants. Whenever possible, it is preferable to have the ability to see the outside from every human-occupied space within a structure. This allows a connection to the outside world which will reduce if not eliminate the feeling of being “cooped up.” The ability to see out offers the body a sense of the time of day, the events of weather, and the feeling of expanded space. In addition, glass also reveals the contents and events within a building to those on the outside. Very often the warmth of the light and spaces within beckon, as well as the ability to see activities unfold from outside. It is far less anxiety-provoking to enter a space that is revealed rather than a space that is opaquely enclosed. No other material available to architects can provide these kinds of psychological responses – the feeling of a greater and larger world, either within or without, to which glass keeps people connected.

4.3.7 Demolition and Recycling

Glass has a very long life as evidenced by the continued existence of glass over the centuries. When glass cracks or needs replacing, any window or glass panel installers will take the used glass with them for disposal. If sorted properly and removed from framing and sealants, it can be sent back to glass factories. Currently, glass used in the construction

industry is rarely recycled. However, clear glass is very well suited for recycling. “The production of new glass can in principle use up to 50% return glass” (Berge, 2000, p.105). If care is used in the removal of the glass from a building during demolition, it is 100% recyclable provided the glass does not contain any low-E coatings. Low-E coated glass can currently be reused in a new project if the dimensions of the unit fit the specifications of the new installation. The use of cullet has been increasing that in some plants, it makes up 40% of the mixture being added to the furnace to form new glass. Applications that do not result in the recycling of old glass into new glass are considered “down-cycling.” “Glass cullet is beginning to be used as a replacement material for sand and rocks in road construction and beach erosion control programs, and for soil as a fill material in landfills” (Demkin, 1998, MAT 08810 p.18). In addition, some fiberglass manufacturers are investigating the use of flat glass cullet in their process. “According to the EPA, the amount of glass recovered from recycling increased 50% between 1985 and 1988” (Demkin, 1998, MAT 08810 p.18). The recyclability of glass is evident throughout its life. “Flat glass manufacturers generate 50,000 to 100,000 tons of glass cullet each year from each manufacturing line and recycle 98% back into the furnace” (Demkin, 1998, MAT 08810 p.18). Additional uses for recycled glass include mixing it into asphalt and cement as sand and aggregate replacements, addition to paint to make the coating reflective, use as sandblast for buildings, recycled into glass tiles for indoor applications, and as filter material in water treatment plants. The most important use for recycled glass from buildings, however, is to bring it back to the beginning of the float glass manufacturing process as cullet for use in new plate glass. This is the only true cradle to cradle use of the material. The benefit of glass is that it is fully recyclable, and can be recycled an infinite number of times. Glass with the low-E coating cannot be recycled at this time. However, this coating is only applied to one side of one of the panes in a window unit. Therefore, with careful removal, the uncoated pane can be recycled into new glass. Since low-E coatings are inert, this pane can be down-cycled for use as sand in other applications. Hopefully in the near future, low-E coatings will be removable allowing all glass panes to be recycled into new glass.

4.3.8 Conclusion

The materials used to produce glass are plentiful in supply and currently have no risk of being depleted. However, the production of glass has a high embodied energy due to the temperatures needed to melt the mixture of constituents. If glass is used in a proper

manner, architects can more than offset the energy used in its production by reducing or eliminating the need for heating and air conditioning, as well as reducing the need for artificial electric lighting within the building. This takes a full life-cycle analysis over the building's 100-year life expectancy to get a full understanding of the offset in emissions and energy usage over the same period.

4.4 Steel

Steel is a strong, durable, and workable material that plays an important role in construction. Used appropriately, "metal can be an enduring material with a longer life span than wood, concrete or plastics" (Calkins, 2009, p.327). "It is made from iron, which in turn is made from iron ore, coal, and limestone, in the presence of oxygen" (Demkin, 1998, MAT 05410 p.2). In the traditional steel-making process, the iron ore, coal, and limestone all require a degree of processing before they are combined to make raw iron. Other materials used in the various processes include nickel, manganese, chromium, and zinc as well as various lubricating oils, cleaning solvents, acids, and alkalines.

"Ferrous alloys, notably steel, are those in which the chief ingredient is the chemical element iron (ferrum)" (Spence, 2011, p.255). Iron (Fe), mixed with other minerals, is found in large quantities in the Earth's crust. To be useful, iron must be extracted from mined ore, have impurities removed and ingredients added to alter its properties, and then be formed into usable products. Iron-based materials account for a substantial portion of manufactured metal items used in construction. "This popularity is based on more than a matter of availability or cost, iron and steel offer a range of properties that fit well with the requirements of the manufactured world" (Lambert, 2009, p.149). They are easy to form and work with, are tough and forgiving in service, resist wear and damage and despite occasional bad press, can be made sufficiently resistance to corrosion. "There are also, and have always been, recyclable iron-based materials – with around 75% of feedstock for the production of new alloys coming from scrap" (Lambert, 2009, p.149).

"With the notable exception of gold and the occasional chunk of meteoric iron, metals are essentially as artificial to nature as plastic bags" (Lambert, 2009, p.148). So once the artificial nature of metals is accepted, the problems of oxidation and corrosion can be better appreciated as they revert back to more stable compounds. "Corrosion is a natural and normal process, reverting the metals to their lowest energy state" (Lambert, 2009, p.148).

Ferrous alloys such as steel have a life that is determined by their creators, humans. Their lifespan is dependent on the tasks they are given to perform and how well they are treated. Put to good use and properly cared for and protected, they can last to 100 years and beyond. The recyclability of steel, without compromising the strength of the new material, is infinite and can be repeated over and over with little consequence to the original material.

Steel has become a ubiquitous material in most modern construction. It is widely used for structural framing, light framing, hardware, roofing, siding, connectors and many more applications. Carbon steel, which is iron containing up to 1.7% carbon, is the most common metal used in the construction industry. With exposure to exterior conditions, steel is susceptible to corrosion and is usually coated or galvanized. “Worldwide, 1.2 billion tons of raw steel was produced in 2006” (Calkin, 2009, p.327). Of this, 96 million tons was produced in the United States, 187 million tons in the European Union and 420 million tons in China. “Steel (and other ferrous alloys such as cast and wrought iron) is popular for more reasons than just being inexpensive or plentiful. Iron and steel offer a range of properties that fit well with the requirements of the manufactured world” (Lambert, 2009, p.149). Steel gives architects and engineers great strengths from fairly small and lightweight (compared to strength) sections and if used properly as a structural material, can reduce the amount of other materials needed to construct a project.

“Steel production involves a significant environmental impact and consumes a great deal of energy. In fact, steel manufacturing and fabrication industries are among the largest and most important consumers of energy and raw materials in the United States” (Demkin, 1998, MAT 05410 p.2). “According to the American Iron and Steel Institute, steel manufacturers shipped 84 million tons of steel products in 1989” (Demkin, 1998, MAT 05410 p.2) and of that total, some 13% - or about 11 million tons – was designated for construction. Because of its strength, durability, flexible uses, and recyclability, the benefits of using steel can outweigh the costs in many applications.

The major constituents for steel production are iron ore or scrap steel, coal, and limestone. In addition, other materials including oxygen, nickel, manganese, chromium, zinc, lubricating oils, cleaning solvents, acids and alkalines are also used in the process. The acquisition and preparation of these materials is described, with a summary of embodied energy and environmental impacts.

4.4.1 Iron Ore

“The main raw material for the production of steel is iron ore. Iron is the second most abundant metal, constituting about 5% of the Earth’s crust” (Demkin, 1998, MAT 05410 p.4). The majority of the domestic iron ore that is used in U.S. steel manufacturing is derived from the Mesabi Range area near Lake Superior in Minnesota, where mining dates back to the 1890s. The increasing importance of recycled scrap steel and the availability of relatively inexpensive iron ore from overseas have both contributed to a decline in domestic iron ore production. “In 1991, 55,516,000 tons of iron ore (99% of which came from the Mesabi Range) were produced in the United States” (Demkin, 1998, MAT 05410 p.4).

“Open pit mining is the main method for extracting iron ore and accounts for more than 90% of present-day extraction. The remainder is extracted from deep, vertical shaft mines” (Demkin, 1998, MAT 05410 p.4). Most open-pit mining is achieved using large power shovels, trucks and drills. Depending on its subsequent use, “crude iron ore is beneficiated to increase its iron content, reduce the content of impurities, or improve its physical structure” (Demkin, 1998, MAT 05410 p.4). If the iron content of the ore is less than 50%, it is too costly to ship any distance. “These lower-content ores are processed on-site by a beneficiation process that removes some of the unwanted elements, leaving an ore with high iron content” (Spence, 2011, p.256). The beneficiation process includes simple crushing, screening, drying, and washing, plus separation of the ore minerals from gangue (worthless rock or vein matter in which metals occur) based on differences in physical or chemical properties.

Soft hematite ores of the Mesabi Range contain 52 – 57% iron, but the fines fraction, consisting of particles of less than ¼ inch in size, must be agglomerated by sintering (causing a coherent mass by heating without melting) before being placed in blast furnaces. “Agglomeration involved pelletizing the ore particles which are then easier to ship than finely ground ore” (Spence, 2011, p.256). The heat used in the combustion during sintering, which ranges from about 2,200 to 2,600 Fahrenheit, causes the particles to fuse together. “The usual way of making pellets is to mix a small quantity of binder (usually bentonite, sometimes hydrated lime) with finely ground concentrate and ball the mixture in rotating drums or disks” (Demkin, 1998, MAT 05410 p.7). These green pellets are then hardened in gas- or oil-fired furnaces or kilns at about 2,400 Fahrenheit. Finished pellets contain

between 63 – 66% iron and withstand the abrasion of handling and transport better than sinter.

Both surface mining and pit mining for iron ore generate a large amount of overburden and unused rock and soil. “At most U.S. taconite mines, 5 to 6 tons of material must be mined for each ton of usable product. Today, with the relatively low grade of crude ore, 3 tons must be processed for each ton of pellets that is produced. Mining impacts are significant in terms of habitat alteration, habitat destruction, and erosion” (Demkin, 1998, MAT 05410, p.8). In addition, mine runoff can result in increased turbidity of local streams and lakes resulting in de-oxygenation and possible fish kill. The combustion of fuel products and the consumption of energy during mining operations, beneficiation, agglomeration, and the transport of sinter or pellets to the blast furnace result in a variety of emissions including sodium dioxide, particulates and carbon dioxide.

“The energy required for drilling, blasting, loading, and transporting iron ore is estimated to range from 49,000 to 104,000 BTUs (52 to 110 MJ) per ton of rock mined” (Demkin, 1998, MAT 05410 p.9). In addition, Demkin (1998) reports that beneficiation results in energy consumption from 218,000 to 664,000 BTUs (230 to 700 MJ) and pelletizing requires an additional 400,000 BTUs (422 MJ) per ton of pellets (MAT 05410 p.9). Sintering adds an additional 1.5 million BTUs (1,582 MJ) per ton of sinter. Therefore, the use of scrap steel will save significant energy in the acquisition stage.

4.4.2 Scrap Steel

Steel is one of the most readily recycled materials, and the use of scrap steel in producing new steel products has increased dramatically over the past several decades. “In the past decade alone, the recycling of scrap steel into steel production has resulted in the reuse here and abroad of 1.2 trillion pounds of steel” (Demkin, 1998, MAT 05410 p.8) and the overall recycling rate for steel recycling is 66%. Basic oxygen furnaces generally use 20 – 30% scrap, while electric ore furnaces use nearly 100% scrap. Steel is 100% recyclable and should always be placed back at the beginning of the steel-making process. “The energy use for recovery and transport of scrap that equates to one ton of ore, pellets and sinter, is about one-third that for the use of the raw materials, or about 600,000 BTUs (633 MJ) per ton of steel produced” (Demkin, 1998, MAT 05410 p.9).

4.4.3 Coal and Coke

“The steel industry is the nation’s largest consumer of coal, using about 42% of all coal shipped from mines: (Demkin, 1998, MAT 05410 p.9). Coke for the manufacture of pig iron from iron ore is produced from bituminous coal, which is primarily mined underground. “Significant technological innovations in recent years have greatly increased productivity in underground mining including widespread mechanization, increased use of highly efficient long-wall machinery, and computerization of operations” (Demkin, 1998, MAT 05410 p.9).

Coal is also taken from underground through conventional mining. This process, which accounts for about 11% of deep-mined coal, consists of a series of operations that involve “cutting the coal-bed so it breaks easily when blasted with explosives, then removing the broken coal from the mine” (Demkin, 1998, MAT 05410 p.9). In areas where geology is favorable, this is the technique that is the most practical and economical.

Once the coal is extracted, it is transported to coking facilities by railroad (60%), barge, or truck. “Transport of coal delivered to market can account for as much as 35 – 50% of the final total cost” (Demkin, 1998, MAT 05410 p.10).

Coal must be prepared before it can be converted to coke. “First the coal is pulverized and screened. It is then blended with several other types of coal, and water or oil is added to control density” (Demkin, 1998, MAT 05410 p.10). Virtually all coke is produced from coal by destructive distillation in a by-product coke oven battery. “The distillation, termed coking, is accomplished in a series of ovens in the absence of oxygen” (Demkin, 1998 MAT 05410 p.10). After a coking time typically between 12 and 20 hours, almost all volatile matter is driven from the coal mass, and the coke is formed. Maximum temperature at the center of the coke mass is usually 2,000 to 2,100 Fahrenheit. A collector transports the volatile gasses from each oven to the by-product recovery plant. “Here, coke oven gas is separated, cleaned, and returned to heat the ovens. Using the coke oven gas to fire the ovens helps conserve energy and reduce emissions” (Demkin, 1998, MAT 05410 p.10).

Both underground and strip mining for coal generate substantial amounts of mine spoils. In underground mining, these spoils are generally left in the mines. In surface and open-pit mining, the spoils are deposited nearby, which creates mounds that alter and disrupt habitats. The volume is often substantial in strip mining because large amounts of

soil and rock are removed to access coal seams. Stabilization and reclamation of coal mines can be very difficult because the spoils contain wastes that are acidic and laden with concentrations of coal that are toxic to many plants and animals. "Some coal deposits contain minerals that pose risks to environmental and human health" (Demkin, 1998, MAT 05410 p.10) such as acid-forming materials, particularly sulfur. Mine spoils can acidify soils, groundwater, and surface water. Additional problems, as noted under iron ore mining, can also cause environmental problems. In addition, the combustion of fuel products, as under iron ore mining, can result in a variety of emissions.

"Energy requirements for underground mining are estimated from 175,000 to 683,000 BTUs (185 to 720 MJ) per ton of rock mined" (Demkin, 1998, MAT 05410 p.11) depending on the method used. This includes the energy used for drilling, blasting, loading, and transporting the coal as well as the energy required for ventilating and heating the mine. "Conversely, the energy requirements for strip mining are estimated between 49,000 and 104,000 BTUs (52 to 110 MJ) per ton of rock mined" (Demkin, 1998, MAT 05410 p.11).

"Energy required for coke making is reported at 6 million BTUs (6,326 MJ) per ton of coke produced. Experts predict a 50% reduction in the energy required for coke making in the early 2010s as a result of technological advances in increases in efficiency" (Demkin, 1998, MAT 05410 p.12). Coke making is one of the most energy-intensive steps in the process of making steel.

4.4.4 Limestone

Limestone used in steel making is processed into lime. Limestone is a sedimentary rock composed mostly of the mineral calcite (CaCO_3). Lime is produced by calcining, or heating the limestone in kilns to a high temperature to drive off any water present and release the carbonate as carbon dioxide. This process is the same as is used in the production of cement for use in concrete (see section 4.2.1).

Fuels are consumed to power the heavy equipment used in the limestone mining and crushing processes. "Estimates of energy use for material acquisition steps, such as mining and crushing, vary with the processes that are used" (Demkin, 1998, MAT 05410 p.15) and are estimated at 164,000 BTUs (173 MJ) per ton. Transportation to steel plants requires 305 to 3,050 BTUs (0.32 to 3.2 MJ) per ton for each mile the load is hauled.

4.4.5 Oxygen

“The iron and steel industry consumes more oxygen than all other industries combined (Demkin, 1998, MAT 05410 p.15). Oxygen has several applications in the making of steel, but its most important use is in the basic oxygen furnace. “In 1988, operation of basic oxygen furnaces consumed 26.7 billion cubic feet of oxygen, accounting for 83% of the industry’s oxygen consumption” (Demkin, 1998, MAT 05410 p.15).

Oxygen for steel-making is manufactured by cryogenic separation which is a liquefaction and rectification of air. “Filtered air is compressed to approximately 520 kPa in a centrifugal compressor” (Demkin, 1998, MAT 05410 p.15). After the water is removed, the remaining air enters a reverse heat exchanger and is cooled to near its dew point. As the air cools, moisture is condensed and frozen on the walls of the heat exchanger. The air that emerges from the reversing heat exchanger is completely dry and has over 99% of the carbon dioxide removed. “Since liquid oxygen evaporates at -300 Fahrenheit, most oxygen plants are located at the steel mills to reduce waste and energy expenditure in the process” (Demkin, 1998, MAT 05410 p.15).

Currently, there is no data available in the waste produced from the manufacture of liquid oxygen. In addition, energy is required to operate the centrifugal compressor and reverse heat exchanger; however, “there is no quantitative data available concerning these energy requirements” (Demkin, 1998, MAT 05410 p.15).

4.4.6 Nickel

Nickel is often added in steel-making to improve the hardenability, low-temperature toughness, and corrosion resistance of the steel. “In 1990, an estimated 83,251 tons of nickel were used for steel-making” (Demkin, 1998, MAT 054110 p.15). Nickel is the Earth’s fifth most abundant element; however it occurs in the Earth’s crust in the range of 0.008% to 0.02% by weight. Nickel deposits generally originate from ultramafic rocks which tend to contain 0.3 percent nickel by weight. “Nickel has very few accessible sources” (Berge, 2000, p.80). Essentially all nickel laterite ores are mined by surface methods; sulfide deposits are generally mined by more costly underground mining methods. Both of these methods produce similar environmental problems and waste as iron ore and coal mining. In addition, “nickel has the property of biological amplification and is particularly poisonous for

organisms living in water. According to a 1985 report by J. Torslov, in the former Soviet Union a connection has been registered between nickel in the soil and the death of forests” (Berge, 2000, p.80). Most of the nickel used in the United States is imported, and domestic reserves of nickel are low.

“The energy required for the surface mining of nickel is estimated to range from 49,000 to 104,000 BTUs (52 to 110 MJ) per ton of rock mined. The estimated energy requirements from underground mining range from 175,000 to 683,000 BTUs (185 to 720 MJ) per ton of rock mined” (Demkin, 1998, MAT 05410 p.16). Both of these amounts include the energy needed for drilling, blasting, loading, and transporting the ore – as well as the energy required for ventilation and heating of underground mines.

“Energy used in the processing of laterite ores represents the most significant cost of recovering nickel from this type of deposit” (Demkin MAT 05410 p.16), however, no quantitative data is available on the specific amount of energy required for processing laterite ores.

4.4.7 Manganese

Manganese is added to steel production for de-oxidation, control of sulfur effects, and hardenability. “Iron and steel making accounted for about 90% of the domestic manganese demand in 1991” (Demkin, 1998, MAT 05410 p.17). “It is essential in the production of steel as between 7 and 9 kilograms (15.4 to 19.8 pounds) are required per ton of steel” (Berge, 2000, p.80). “According to the Bureau of Mines, there are two major land-based resources of manganese: chemical sediments and secondary enrichment deposits” (Demkin, 1998, MAT 05410 p.17). Most manganese ore is mined by mechanical operations and standard earth-moving equipment is used for these surface mines. Underground mining is also used for manganese and is generally done by room-and-pillar techniques.

Techniques such as crushing, screening, washing, jigging, tabling, flotation, and heavy-medium and high-intensity magnetic separation have been used to upgrade raw manganese ore into usable concentrates. Electrothermy is the predominant method for manufacturing manganese ferroalloys and employs the use of a submerged-arc furnace. “The metal is commonly produced by electrolyzing a solution of manganese sulfate prepared from ore that has been reduction roasted” (Demkin, 1998, MAT 05410 p.17).

The environmental impacts associated with manganese mining are similar to those associated with other types of surface and underground mining previously mentioned. Particulate emissions of manganese from crushing could pose some risk to health. “According to the Environmental Protection Agency, manganese is an essential element for people, animals, and plants, but in excess amounts it can be harmful to the respiratory and nervous system” (Demkin, 1998, MAT 05410 p.17). The United States has been lacking manganese reserves since the start of domestic steel production and currently most, if not all of the manganese used in the production of steel is imported.

“The energy required for the surface mining of manganese is estimated to range from 49,000 to 104,000 BTUs (52 to 110 MJ) per ton of rock mined” (Demkin, 1998, MAT 05410 p.17) and for underground mining range from 175,000 to 683,000 BTUs (185 to 720 MJ) per ton of rock mined. This includes the energy required for drilling, blasting, loading, and transporting the ore, as well as the energy for ventilation and heating of any underground mines. Currently there is no data on the amount of energy required for the beneficiation of manganese.

4.4.8 Chromium

“Chromium is often added to steel to improve hardenability, high-temperature strength (such as during a fire), and corrosion resistance” (Demkin, 1998, MAT 05410 p.15). It is the sixth most common element and is derived from the mineral chromite which is not mined domestically. Therefore, the United States is dependent on imports and recycling to meet domestic chromite demand. “In 1990, domestic consumption of chromite ore and concentrate was 402,290 tons” (Demkin, 1998, MAT 05410 p.18).

Once the ore is mined, it is beneficiated. The amount required and the techniques used depend greatly on the ore source and the ultimate use. When chromite is clean only hand sorting is required. However, according to the Bureau of Mines, “when mixed with host rock, heavy-media separation or crushing may be used along with gravity and magnetic separation” (Demkin, 1998, MAT 05410 p.18). With the end-use of steel production in mind, chromium must be extracted from the chromite mineral. “This is accomplished by smelting chromite ore to produce ferrochromium” (Demkin, 1998, MAT 05410 p.18). Technically, the oxygen is removed from the iron-chromium-oxygen mineral leaving an iron-chromium alloy and ferrochromium. The dominant method for accomplishing this is the submerged-arc

furnace. Modern furnaces are closed systems rather than open systems which improves pollution control, efficiency of the furnace itself, and safety.

Recycling is the only domestic supply source for chromium. “Stainless steel and super alloys are recycled, primarily for their nickel and chromium contents” (Demkin, 1998, MAT 05410 p.18). As much as 50% of stainless steel production results from recycled stainless steel scrap. According to the Bureau of mines, the United States “recycled about 561,000 tons of stainless steel scrap and imported about 742,000 tons of chromite ore and ferroalloys in 1990” (Demkin, 1998, MAT 05410 p.18).

The environmental effects of chromium mining are similar to those associated with other types of surface and underground mining and will not be repeated here. “Considerable electricity is required for the smelting chromite ore, the cost of which accounts for up to 55% of the smelting cost” (Demkin, 1998, MAT 05410 p.18). The air emissions from the generation of electricity include volatile organic compounds, sulfur dioxide, nitrous oxides and carbon dioxide. In addition, untreated chromium wastes are toxic. Therefore, “the EPA requires that chromium-containing residues from the roasting or leaching of chrome ores be treated” (Demkin, 1998, MAT 05410 p.18).

“The energy required for the surface mining of chromium is estimated to range from 49,000 to 104,000 BTUs (52 to 110 MJ) per ton of rock mined” (Demkin, 1998, MAT 05410 p.17) and for underground mining range from 175,000 to 683,000 BTUs (185 to 720 MJ) per ton of rock mined. This includes the energy required for drilling, blasting, loading, and transporting the ore, as well as the energy for ventilation and heating of any underground mines. In addition, “ferrochromium production is an energy-intensive process, requiring about 40.5 million BTUs (42,722 MJ) per ton of product” (Demkin, 1998, MAT 05410 p.19). Currently, the available technology can reduce the energy requirement to about 21.3 million BTUs per ton by thermal energy recovery and recycling. Other technologies are being explored to further reduce the energy demand of chromium production.

4.4.9 Zinc

Zinc is required for galvanizing steel. It is a medium-hard, bluish-white metal that is characterized by brittleness and very low strength. The United States is the world’s largest producer and consumer of zinc. “In 1990 approximately 85% of the zinc produced in the

United States came from Alaska, Missouri, New York, and Tennessee; and approximately 52% of the total slab zinc was used for galvanizing” (Demkin, 1998, MAT 05410 p.19). It is abundant in the Earth’s crust and is found primarily as the sulfide ore sphalerite (ZnS). The majority of zinc is mined from surface mines using the open pit method. “In ordinary air conditions, one can assume a lifespan of 100 years for normal coating but only a few years in sea air, damp town air or industrial air” (Berge, 2000, p.79).

“The ore typically contains from 3 – 11% zinc. The ores must be concentrated before recovering the metal. To accomplish this, the ore is first crushed and ground to separate ore from waste rock physically. It is then processed by flotation to separate the zinc mineral sphalerite from lead, copper, and iron sulfides” (Demkin, 1998, MAT 05410 p.19). The zinc concentrates are then thickened, filtered, and dried before being processed into metal. “Concentration generally brings the ore to 49 – 54% zinc” (Demkin, 1998, MAT 05410 p.19). Zinc ores are then processed into metallic slab zinc.

The principal environmental concerns associated with the material acquisition and production for zinc include those for strip and pit mining as previously discussed. In addition, the combustion of fuel products and the consumption of energy during mining and crushing operations plus the transportation of the ore to the steel mill result in the same concerns as other mining and transportation operations produce. The wastewater from zinc production facilities can contain various metals and organics, such as lead, cadmium, chromium, zinc, copper, silver, selenium, methylene chloride and other toxic chemicals. “A number of zinc smelter facilities have been listed as Superfund sites” (Demkin, 1998, MAT 05410 p.21). Currently, there is an abundance of zinc ore in the United States to meet demand.

Estimates of energy use for materials acquisition, including mining, crushing, and transporting, vary with the processes used. “The energy requirements for strip mining are estimated to fall between 49,000 and 104,000 BTUs (52 to 110 MJ) per ton of rock mined. The energy required for concentration is estimated at 1.7 million BTUs (1,793 MJ) per ton of enriched ore. The cost of transportation is a function of distance and varies considerably, but a widely accepted estimate is 500,000 BTUs (527 MJ) per ton delivered to the steel mill” (Demkin, 1998, MAT 05410 p.21).

4.4.10 Steel Manufacturing

In conventional steel making, iron is produced in blast furnaces by smelting and the reduction of iron ore with a hot gas. "Smelting is a process in which the ore is heated, permitting the iron to be separated from impurities with which it may be chemically or physically mixed" (Spence, 2011, p.256). "The large refractory-lined furnace is charged through its top with iron ore, pellets and/or sinter; limestone, dolomite, and sinter as flux; plus coke for fuel" (Demkin, 1998, MAT 05410 p.22). These materials react with the blast furnace air to form molten reduced iron, carbon monoxide, and slag. "Reduction is a process that separates the iron from oxygen with which it is chemically mixed" (Spence, 2011, p.256). The resulting material is referred to as pig iron. "A large, modern blast furnace can produce 1000 tons of pig iron every 24 hours" (Berge, 2000, p.76).

"In the basic oxygen process (BOP), molten iron from a blast furnace and iron scrap are refined in a furnace by the lancing, or injecting, of high-purity oxygen" (Demkin, 1998, MAT 05410 p.22). Coal, oil, and natural gas are the "commonly used fuels in a blast furnace and most operate on coke, which is produced from coal" (Spence, 2011, p.256). The oxygen reacts with carbon and other impurities to remove them from the metal. The reactions are exothermic which means that no external heat source is necessary to melt the scrap and to raise the internal temperature of the metal to the desired range for tapping. A full furnace cycle typically ranges from 25 to 45 minutes.

"Electric-arc furnaces (EAFs) are used to produce carbon and alloy steels" (Demkin, 1998, MAT 05410 p.23). The input material to an EAF is typically 100% scrap. "Several cylindrical electrodes project into the furnace from the top" (Spence, 2011, p.259). Electric current generates heat between the electrodes in the furnace and through the scrap. After the melting and refining periods, the slag and steel are poured from the furnace by tilting. "Cycles, known as heats, range from about 1 ½ to 5 hours to produce carbon steel and from 5 to 10 hours or more to produce alloy steel" (Demkin, 1998, MAT 05410 p.23).

The open-hearth furnace is a shallow refractory-lined basin in which scrap and molten iron are melted and refined into steel. The typical mixture in this process is 50% scrap and 50% molten iron. Gas burners above and at the side of the furnace provide heat to melt the mixture. Refining is accomplished by the oxidation of carbon in the metal and the formation of a limestone slag to remove impurities. "The steel product is tapped by the

opening of a hole in the base of the furnace with an explosive charge” (Demkin, 1998, MAT 05410 p.23). The open-hearth steel-making process normally requires 4 to 10 hours for each heating.

Direct steel making refers to a process in which the iron ore agglomeration and the coke-making, iron making, and BOF or open-hearth furnace process are eliminated. “Coal (rather than coke), iron ore, and lime flux are fed directly into an autogenous reactor to produce iron that contains 2% carbon” (Demkin, 1998, MAT 05410 p.24). Direct steel making is not being used to any extent in the United States at present, but can greatly reduce the energy required for producing steel.

“On average, for conventional steel making, a ton of steel requires approximately 2.5 tons of materials. Blast furnace production requires 3,170 pounds of iron ore, 300 pounds of limestone, 900 pounds of coke, 2,575 pounds of air, 80 pounds of oxygen and 100 pounds of hydrocarbon fuel to fire the furnace for every ton of raw iron that is produced” (Demkin, 1998, MAT 05410 p.25). The steel industry is a significant source of industrial pollutants discharged into water, air and land. The considerable wastes the industry generates take the form of solid and liquid by-products of processing as well as air emissions and wastewater discharges. In addition, every steel plant operation requires energy in the form of heat or electricity. As previously discussed, this also produces environmental hazards. Scrap waste from cutting, drilling and grinding operations is recyclable and is usually collected and added to the scrap feed for the furnace. Steel is one of the most readily recycled materials, and the amount of recycling is increasing dramatically.

The manufacture of steel requires substantial amounts of energy. “Energy used in primary iron and steel manufacture accounts for 2.3% of total U.S. energy consumption and 9% of all U.S. manufacturing energy use” (Calkin, 2009, p.331). Pound for pound, it is one of the most energy-intensive materials. “On average, an estimated 22 million BTUs (22,725 MJ) are expended for each ton of finished steel produced” (Demkin, 1998, MAT 05410 p.27). This varies with process, and a great deal of savings in raw materials and energy can be achieved by recycling steel products. The largest single energy expenditure in steel making is for the manufacture of pig iron from iron ore. “This process requires approximately 13.9 million BTUs (14,662 MJ) per ton of iron” (Demkin, 1998, MAT 05410 p.27). This same source reports that raw steel production requires approximately 15.9

million BTUs (16,772 MJ) per ton of steel when a basic oxygen furnace is used, 15.2 million BTUs (16,034 MJ) per ton of steel when an open-hearth furnace is used, and 6.2 million BTUs (6,540 MJ) per ton of steel when the electric furnace is used. Casting requires an additional 1.6 million BTUs (1,688 MJ) per ton of steel.

When recycled scrap can be substituted for pig iron in steel making, energy can be saved in blast furnace processing. Electric furnace production of steel from scrap only requires 6.3 million BTUs (6,645 MJ) per ton of steel which is 39% of the energy requirement for the BOF process simply by using scrap for the source materials because it requires no energy for iron making.

Finally, direct steel making should be an advance that replaces the iron ore agglomeration, coke making, iron making, BOF, and open-hearth furnace process with direct measures. This approach in which the energy expenditure in steel making can be reduced 37 – 43% and was supposed to be in use by the year 2010. Unfortunately, this has not occurred and the reasons are unknown. “Direct steel making requires 9.9 million BTUs (10,443 MJ) per ton of steel, considerably less than conventional production methods” (Demkin MAT 05410 p.29). Data is not currently available on the energy required for the galvanizing process.

4.4.11 Steel Fabrication

Hot and cold rolling is one process of fabrication, which takes place at temperature ranges of 1,470 to 2,150 Fahrenheit. “At this temperature, steel is plastic and particularly malleable and therefore its thickness can be greatly reduced with relative small force” (Demkin, 1998, MAT 05410 p24). There are two stages in the modern process of rolling: roughing and finishing. Roughing takes place at the high end of the temperature range and thicknesses of 10 inches are reduced to 1 to 2 inches. Finishing then occurs at the low temperature end which reduced the thickness to 0.08 to 0.12 inches. “The results are coils up to 2,000 feet long or components of greater thickness or irregular cross section and varying length” (Demkin, 1998, MAT 05410 p.24). Hot rolled steel is normally cleaned in a bath of sulfuric or hydrochloric acid to remove the surface oxide scale that forms during hot rolling which is generally a continuous process.

“In cold rolling, the hot rolled coils are rolled again to make them thinner and smoother. This process gives the steel a higher strength-to-weight ratio than hot rolling” (Demkin, 1998, MAT 05410 p.24). Cold rolling can reduce a 0.10 inch thick coil that is $\frac{3}{4}$ mile long to a 0.03 inch thick coil more than 2 miles long in about 2 minutes. Cold rolling increases the hardness and yield strength, reduces the ductility and formability. “The cold rolling process hardens sheet steel so that it must be heated in an annealing furnace to be rendered more formable” (Demkin, 1998, MAT 05410 p.24). For batch annealing, the heating and re-cooling of the sheets may take 5 or 6 days. Continuous annealing takes only 2 minutes but requires much higher heating and cooling rates. After the steel has been softened in the annealing process, a temper mill can give the steel the desired flatness, metallurgical properties, and surface finish. The product is then recoiled and shipped or further trimmed or sheared into other shapes and lengths.

Fabricated steel systems may be painted or galvanized. Painting is usually done in a continuous fashion. “Galvanizing is the process by which a thin protective coat of zinc is applied to steel to protect it from corrosion” (Demkin, 1998, MAT 05410 p.25). Should any part of the steel become exposed to the outdoors, galvanic reaction between the zinc and steel or iron causes the zinc to corrode and form compounds that cover and continue to protect the steel as long as zinc remains. Zinc coatings are applied by hot dipping, electro galvanizing, spraying and sherardizing. Continuous hot-dip galvanizing is the current industry standard. In continuing hot-dip galvanizing, sheet steel is coated with a versatile zinc coat that not only is highly corrosion resistant, but also acts as an excellent surface to accept paint.

Forming involves cutting, bending, welding, machining, and various other processes to manufacture the desired shape and configuration of the structural steel framing. Like other steel-making processes, these are almost totally mechanized and automated. Forming, finishing, treating, and annealing add an average of 4.6 million BTUs (4,852 MJ) per ton of finished steel to the energy requirements.

4.4.12 Steel Construction

Steel construction is generally carried out by cranes, welding equipment or power tools used for tightening connections. “For prefabricated steel frames, very little waste is generated at the job site during installation” (Demkin, 1998, MAT 05410 p.31). There may

be some solid waste from members that are damaged or were fabricated in error, however these members are generally brought back to the fabricator to be used as scrap and can easily be recycled into new steel.

A small amount of air emissions results from the electricity or other energy used to power equipment for welding and other fastening systems. In addition, transportation of members to the job site involves the use of fuels that can cause emissions as previously described. In addition, steel framing does not outgas and therefore does not affect indoor air quality.

There is no data available on the amount of energy required to deliver and install steel framing and there is little indication that excessive amounts of energy are required. In the state of Oklahoma, most steel is distributed from suppliers in Oklahoma City and Tulsa. Oklahoma City is approximately 69 miles from Weatherford, Oklahoma making the travel distance for delivery negligible.

4.4.13 Use and Maintenance

During the life of a steel frame building, the steel itself needs little to no maintenance and does not affect the indoor air quality or health of any occupants. Maintenance requirements, however, are an important consideration in metal selection, as the structure will be in use for a long period of time. "Cleaning and maintenance of metal surfaces can extend the life span of a metal structure and reduce the risk of corrosive staining of metals and metal runoff pollution" (Calkins, 2009, p.368). Since contaminants must remain on the surface of a metal long enough and in high enough concentrations for corrosion to occur, regular manual cleaning can extend its life considerably. Because of the incredible strength of structural steel, if designed and engineered correctly, will last far beyond the usefulness of the structure in which it is installed. Therefore, it is important to use a fastening system in the structure that can be easily disassembled. This would require bolts instead of welds for ease of deconstruction for reuse or recycling.

As has already been discussed, steel has a similar life cycle to the people who use it. "For steel, corrosion represents the biggest threat to a long and healthy life" (Lambert, 2009, p.162). "Iron and steel products that are not exposed to corrosive environments usually last for very long periods. When ordinary steel is exposed to damp air, water, acids or salt

solutions, it rusts. This is hindered by coating it with zinc, tin, aluminum, cadmium, chrome or nickel through coating or galvanizing” (Berge, 2000, p.76). Processes such as general, pitting, crevice, galvanic, and high-temperature corrosion are a problem with steel in different environments and applications. “The most commonly employed method of protecting metals from corrosion is to apply a protective coating” (Lambert, 2009, p.166). These coatings such as lead and chromium have been phased out and systems with high solvents are being replaced by water-based coatings that are easy on the environment. The two most popular systems for galvanizing steel for use in concrete outside in the environment have been zinc and fusion-bonded epoxy. “These two processes, zinc coating and galvanizing, are considered serious environmental polluters” (Berge, 2000, p.77). In both cases there is an emission of organic solvents, cyanides, chrome, phosphates and fluorides from the rinse water. “One method for relatively pollution-free galvanizing is a process making use of the natural occurrence of magnesium and calcium in sea water” (Berge, 2000, p.77). The technique simply involved dropping the negatively-charged steel into the sea water and switching on the electricity. The method is effective for underwater structures that have contact with salt water. However, it is not known whether this technique gives lasting protection on land. Another way of protecting steel that is environmentally friendly is giving it a ceramic coating.

Steel used for reinforcing is generally not galvanized. “Concrete provides adequate protection against corrosion” (Berge, 2000, p.77). Even concrete can disintegrate over time and the reinforcement can become exposed. Correct casting of concrete or using high fly ash content should give a very functional lifespan as long as the concrete provides continued reinforcing cover.

4.4.14 Demolition and Recycling

“The potential for nearly endless recycling may be the most sustainable characteristic of metals” (Calkins, 2009, p.327). Steel is one of the most economical materials to remove from the solid waste stream for recycling. Magnetic separation is all that is required to obtain steel from any construction or demolition debris. “Most metals can be recycled multiple times into very high-value applications without compromising performance or down-cycling” (Calkins, 2009, p.362). In fact, “steel loses none of its inherent physical properties during the recycling process” (Spence, 2011, p.262). During

the last decade, more than 1 trillion pounds of steel scrap have been recycled, “extending the life of the nation’s landfills by more than three years” (Demkin, 1998, MAT 05410 p.31). In 2000 for example, “80.7 million tons of metal were recycled, valued at \$17.7 billion” (Calkins, 2009, p.362). Also according to Calkins (2009), steel as a construction material is recycled at a rate of 75.7% in 2005” (p. 362). There are no limitations on the reuse of steel in new products. Coatings or other foreign materials on the original may add minor contaminants to the new production process. “Such contaminants are minor considerations in view of the possible energy and resource savings involved in recycling” (Demkin, 1998, MAT 05410 p.31). For every pound of steel that is recycled, 5,450 BTUs (5.7 MJ) of energy are conserved. “The Steel Recycling Institute estimates that in one year, the U.S. steel industry saves the equivalent energy to power 18 million homes by using recycled steel” (Calkins, 2009, p.362) and that the use of recycled steel also saves resources, with a ton of recycled steel saving 2500 pounds of iron, 1400 pounds of coal, and 119 pounds of limestone. It is important to note that recycling scrap does not eliminate the release of pollutants, toxins and emissions into the environment. However, significant decreases in these releases are achieved by using scrap instead of virgin materials. In addition, zinc can be recovered from both new and old galvanized steel scrap. Recycling of metals continues to be a major industry. “Prevention of corrosion, particularly of ferrous materials, needs to be given higher status alongside recycling as a sustainable way of obtaining the maximum benefit from the energy invested in a metallic component” (Lambert, 2009, p.170). Recovery of zinc has also risen dramatically over the past decade.

Because scrap steel is generally trucked to the disposal site or recycling center (the latter being the only good choice), energy for truck fuel and the air emissions associated with transport are the major environmental concerns associated with recycling. “The United States steel industry relies heavily on recycled steel, and the reuse of scrap steel has very positive environmental effects, including a 47% reduction in oil use, an 86% reduction in air emissions, a 76% reduction in water contaminants, a 40% reduction in water use, and a 97% reduction in mine wastes” (Demkin, 1998, MAT 05410 p.32). Although the disposal of un-recycled steel poses no particular environmental hazards, recycling steel is the only practice that should be employed with any scrap steel products.

4.4.15 Conclusion

Steel is and remains an important material in the construction of buildings, especially in urban areas, as well as a reinforcing mechanism for concrete structures. In the construction industry the value of recovered structural steelwork and reinforcing bars ensures that they enter the recycling system. Reuse rather than recycling of rolled steel sections is an even better use of the material and saves the section from re-entering the energy-intensive production process; however this remains relatively rare as most sections are delivered to the site in custom sizes for a specific project.

Though steel still contributes extensively to pollution problems with air, water and soil and uses copious amounts of energy, the steel industry has made progress toward reducing these emissions and energy use. "In a 2000 report for the Department of Energy, the steel industry claims to have spent \$10 billion over the past 30 years to improve its environmental record, with 65% of that going to controlling air emissions to comply with the 1990 Clean Air Act" (Calkins, 2009, p.368). Their investments have paid off in some areas. Over 95% of the water used in producing steel is recycled, discharges of air and water pollutants have been reduced by over 90%, and the recycling rate of steel has reached 75.7% and is expected to continue to increase.

4.5 Bamboo

Bamboos occur as prominent elements of natural vegetation in many parts of the tropical, subtropical, and mild temperate regions of the world. "Bamboos are tall, tree-like grasses with durable woody or branched stems" (Asif, 2009, p.51). They generally grow from latitudes inclusive of 47 degrees south to 46 degrees north and grow well in elevations from sea level to over 13,000 feet. "Approximately 34.6 million acres of the Earth's surface are covered with bamboo" (Cusack, 1999, p.7). "Their natural distribution is very uneven, both as to abundance and variety of kinds in a given area" (McClure, 1972, p.1). Through human action and intervention, the distribution of many species of bamboo has widened considerably. Although the greatest concentration of bamboos and the highest development of their use occur on the southeastern borders of Asia and the adjacent islands, some 200 species are also native to the Western Hemisphere. "The natural distribution in this area extends from the southern United States to Argentina and Chile" (McClure, 1972, p.1). "Bamboos are as American as maize, chili peppers and mountain lions" (Judziewicz, 1999,

p.2). They grow as native plants from the temperate forests near Washington, D.C., in the United States to the southern beech forests of central Chile. “The number of species in the Americas actually rivals the number in Asia, and in structural and evolutionary diversity New World bamboos surpass their Old World counterparts” (Judziewicz, 1999, p.2).

“About 20 million tons of bamboo is harvested each year, primarily for local use in papermaking, building, furniture, edible shoots, and a multitude of other uses” (Cusack, 1999, p.7). In 1988, the annual global revenue generated from bamboo is estimated at \$4.5 billion. Bamboo grows very rapidly with little more needed than water which is generally supplied adequately through natural rainfall. Culm (the stem or “pole” of a bamboo plant) growth rates and heights vary among species and with environmental conditions, and can be quite impressive. For example, “one investigation in Japan measured a culm that grew over 47 inches in 24 hours; more typical daily growth rates range between 3 and 16 inches for the larger bamboo species” (Calkins, 2009, p.425). “Bamboo produces four times more wood than, for example, oak” (Schmitt, 1999, p.194). Whenever bamboo is used, a valuable contribution to the environment is made as slower growing hardwood forests are left untouched. Bamboo can be harvested every 3 to 6 years if handled properly, and will grow back from the same rhizome without being replanted. This can be done an infinite number of times without harming the rhizome’s ability to produce a new shoot and has little impact on the soil and nutrients as bamboo can grow in relatively poor soil as long as rainfall is adequate.

There are approximately 1500 species of bamboo in the world which are classified into two main types: clumping (monopodial) and running (sympodial). Clumping bamboos are more versatile in their nature and applications than running ones. Clumping bamboos tend to grow faster than running varieties. “Clumpers invest their energy into taller clumps and above-ground vegetation” (Cusack, 1999, p.13). They develop mature-sized culms in about 4 years, half of the time it takes the runners which generally take 8 years. Bamboo grows from an underground set of roots called a rhizome. Each clumping rhizome produces a single shoot that develops into a culm in the same year or season that it grows from the bud. Running bamboos put 75% of their energy toward creating their underground rhizome system to ensure the ultimate spread of the whole forest, rather than into development of the individual plant. “Therefore, above-ground growth, for runners, is a lower priority to the long-term conquest of taking over the area” (Cusack, 1999, p.13). This is the main reason

that bamboos are considered invasive species by many in the United States. Running bamboos are invasive. There are locations where monopodial bamboos (the runners) have popped up from under the fence next door. Therefore, “running bamboos should never be planted without having a soundly based management system in place prior to planting, and never where they can run amongst other plant species worth preserving” (Cusack, 1999, p.14). Once established, runners are very expensive and difficult to eradicate, requiring either hand digging or bulldozing of all the rhizomes. Clumping bamboos by contrast are not invasive. “The ultimate maximum size and shape of any sympodial species can be predicted, and they cannot self-propagate beyond where they are planted” (Cusack, 1999, p.15). In addition, most clumping bamboos require minimal clump maintenance. “Many of the smaller or medium decorative clumpers require no maintenance other than what is given to other plants in that environment. Simple clump management techniques applied to some of the larger or more vigorous clumping bamboos will benefit both the owner and the plant, but they will remain where they were planted as they cannot self-propagate from roots or rhizomes” (Cusack, 1999, p.15).

Running bamboos are also structurally inferior to clumping bamboos by a wide margin. The anatomical structure of running bamboos is of a vascular bundle and cell arrangement containing fewer fiber bundles (with shorter fibers). Clumping bamboos grow more fibers (that are woody in nature) of longer lengths and grow much larger and taller than running species. The giant clumping bamboos grow larger than running species and are much thicker in diameter making their structural properties favorable for the building industry.

One species, *Guadua angustifolia*, which is native to Peru, Colombia and Ecuador, is of particular interest to the construction industry. “Of all American bamboos, *Guadua* is the most frequently used in construction owing to its superior mechanical and tensile strength, low weight, ease of handling and processing, and low cost” (Judziewicz, 1999, p.91). It is distinctively different in its appearance to other bamboos and is easily identified by short internodes (the length of the actual node between sections), and bright white internode collars which contrast against the dark green smooth surface of the culms that climb 5 to 6 meters (16 to 20 feet) into the air without a branch or a leaf. “*Guadua* contains some 30 varied species, the *Guadua angustifolia* being one of the great structural bamboos of this world” (Cusack, 1999, p.29). It is a spectacular, straight and tall species growing 25 meters

(82 feet) high and 200 millimeters (7 to 8 inches) in diameter. “The Columbian architects O. Hidalgo Lopez and S. Velez are very advanced in the way they are using this bamboo to produce modern buildings, having built more than 40 buildings ranging from houses and factories to shopping arcades” (Cusack, 1999, p.29). Guadua is also more resistant to beetles and fungal rots than other species, but it is still desirable to treat this bamboo as all others to prevent these issues in other environments.

The guadua provides countless environmental services other than its use in the construction industry. “It conserves the soil, controls erosion, regulates the flow of rivers and streams, supplies organic material, and contributes to biodiversity by offering a diverse habitat to flora and fauna” (Londono, 2003, p.31). It also acts as a carbon dioxide sink and produces more oxygen per acre than any other plant on the planet.

“The very strong natural fibers of the Guadua angustifolia make it among the 20 best species of bamboo in the world” (Londono, 2003, p.32). It has been shown that with its incredible fibrous structure, one may develop products such as panels including plywood, laminates, boards and planks; as well as supportive structures for houses and other buildings. “Bamboo panels, especially floors, are more and more in demand all over the world, because they have the texture of marble and the elegance of wood; in addition, they are strong, durable, smooth, clean, non-sliding and resistant to humidity” (Londono, 2003, p.32).

Bamboo is a rapidly renewable material as it tends to use less land and have a faster economic cycle than materials that grow in longer spans. A material can be considered rapidly renewable if the growing span is less than 10 years from seed to harvest maturity. “The intent for using these types of materials is to reduce the use and depletion of finite raw materials and long-cycle renewable materials with replacing them with rapidly renewable ones” (Haselbach, 2010, p.222). Most applicable construction materials are not made from 100% rapidly renewable materials, but rather are composites such as bamboo planks. Therefore the rapidly renewable is only a percentage of the total material in the finished product.

4.4.1 Raw Materials

“Because bamboo plants are generally grown with few chemical inputs, impacts associated with their cultivation are very low” (Calkins, 2009, p.426). The harvesting of bamboo is a simple yet labor intensive process. This is accomplished during the fall or winter months when the majority of the growing season has ended and the sap content is at its lowest. The sap content must be low so the plant has enough energy to begin the growth process once again in the spring. This also means less time and energy is required to dry the bamboo.

The majority of bamboo is cut by hand which can contribute to cost as labor is often an expensive component in the price of building materials. Whether this is accomplished with a hand saw or with the assistance of a powered chain saw is not the issue - and both work very well. There are two reasons that bamboo is cut by hand. The first is because all cuts need to be made right below the second or third node joint so that the plant will completely regenerate. Cutting it any lower, or at ground level, can damage the rhizome and make it impossible for regeneration. The second reason is that heavy equipment in and around bamboo groves can crush young shoots that are coming up and compact the soil which damages rhizomes that grow and regenerate less than 2 feet below grade level. The bamboo poles are then transported to a manufacturing plant, which is often on-site or very nearby.

When considering bamboo for timber sales, growers should be aware of a few things that can damage bamboo’s potential. First, “all immature culms sold will be vulnerable to beetle attack, shrinkage and cracking from high moisture content, or be structurally low in strength” (Cusack, 1999, p.186). Second, consumers must be advised that bamboo cannot be used outdoors and give a long life without proper chemical treatment. Improper farming techniques, premature harvesting, and improper end-use can damage not only the possibilities bamboo presents as a building material, but also the environment in which it is cultivated and harvested.

The energy consumed in the harvesting of bamboos for use in the construction industry is extremely minimal and generally involves a small amount of fuel to power chain saws used in the process. Therefore, the energy involved is negligible and does not contribute to the embodied energy of finished bamboo products. The energy for

transportation to manufacturing is also minimal as plants tend to be nearby and therefore does not contribute substantially to the embodied energy of bamboo in general.

4.4.2 Manufacturing

The manufacturing process varies, depending on the end-use of the bamboo product. Pieces used for structural support are kept as poles whereas those destined to be processed into planks, flooring or plywood undergo a different process. For planks and plywood, the process is very similar to the manufacturing of softwood plywood. There is very little reliable information in print regarding the manufacturing of bamboo into planks (the type that would be used for the sunshade slats) and therefore, much of the data will come from the manufacturing of plywood and other laminated wood products.

For planks, which will make up the shading devices for the Tribal College, a laminating process is used. As the logs arrive at the manufacturer, they are sliced lengthwise by hand with a device called a culm splitter which looks similar to an apple slicer, having 6 to 12 sections. "A culm splitter is simple and effective and cuts culm lengths very quickly into 6 or 8 longitudinal split sections depending on the number of spokes in the tool" (Cusack, 1999, p.125). Some high-yield production facilities have an automatic feeder for the logs that feed them through a slicer. After slicing, the strips are cut to the exact width and length needed and are fed through a grinder that strips down the faces of each strip to expose the fiber.

The strips are then placed in a boiler with a high temperature liquid, usually a boric acid solution, to eliminate remaining saps and sugars, plus any insects that may be in the bamboo fibers. The processing using boric acid is less expensive and less harmful to humans than the more common copper-chrome-arsenic composition that was previously used (and recently outlawed) used for timber and hardwoods. This process causes a slight weakening of the material, but the final strength is not determined by this process. A well-executed treatment can increase the lifespan of bamboo that is exposed to the environment up to 15 years, and those in a closed indoor environment up to 25 years.

From the boric bath, the strips are then placed in a high-temperature and high-pressure steamer, which affects the coloration of the bamboo. The longer the strips are in the steam, the darker the color and consequently, the softer the material becomes. From

the steaming process, depending on the manufacturer, they are either left to dry in the open air or they are placed in a kiln to be dried. There is no evidence as to which way is better to maintain the hardness of the bamboo, time is the only defining factor. It can take about a day to dry in a kiln, or up to a week in the open air.

Once dry, the strips are laid out either horizontally to show natural differentiation in grain, or vertically to create a more uniform look. Binding glue is wiped across all surfaces of the strips which are then pressed together under high pressure by a laminating machine. “A perceived disadvantage to phenolic adhesives is their formaldehyde gas emissions. These emissions are regarded as carcinogenic although the concentrations from all wood products are well below any level that would cause concern” (Milner, 2009, p.206). Well-manufactured phenolic resins are widely regarded as the most durable of wood adhesives. They are widely accepted to be as durable as the wood substrate they bond together and provide a benchmark against which other wood adhesives are compared (Milner, 2009, p.206). Phenolic adhesives consist of phenol formaldehyde resins which are waterproof and extremely durable – suitable for outdoor and indoor use in construction. “Although emissions from the production process are usually controlled, phenol and formaldehyde monomers may sometimes be released into wastewater, possibly having ill effects on human health” (Demkin, 1998, MAT 06118 p.15). Indoor air quality and the off-gassing of materials is a concern with regard to sustainability. “Phenol formaldehyde resin adhesives, which are used in the laminating of bamboo into planks, are more stable than most and emit such negligible amounts of formaldehyde that these products are not considered to have a significant impact on indoor air quality” (Demkin, 1998, MAT 06118 p.17). Exposure to significant amounts of formaldehyde has been associated with a number of effects on human health including eye, nose, throat, and skin irritation; nausea; headaches; and allergic reactions. “The national Toxicology Program, in its Seventh Annual Report on Carcinogens, concludes that formaldehyde can be reasonably anticipated to be a carcinogen” (Demkin, 1998, MAT 06118 p.17). With this concern in mind, glues and laminates can be specified in the manufacturing process that are formaldehyde free and contain no volatile organic compounds that off-gas into the indoor air.

The strips are now formed into large sheets of bamboo which are cut to their desired sizes, shapes and lengths. From cutting, they are then moved to the final step where the

planks are coated with an aluminum oxide solution which is the standard solution used on wood flooring and other laminated wood products.

“A recent study examined the environmental impacts of bamboo used in Western Europe by conducting a life-cycle analysis of bamboo culms from Costa Rica and bamboo panels produced in China” (Calkins, 2009, p.427). The culms were compared with steel, concrete, and sustainably harvested lumber used in pedestrian bridges. “The life cycle analysis revealed that most of bamboo culms’ environmental cost is associated with transporting the materials overseas from Costa Rica to Europe” (Calkins, 2009, p.427). This analysis went on to estimate that the annualized environmental costs of bamboo culms are lower than that of steel, concrete and lumber. This particular analysis estimated that “the environmental costs of steel and some types of lumber are about 20 times higher than bamboo, and the annualized environmental cost of concrete is about 12 times higher” (Calkins, 2009, p.427). Therefore, it is evident that environmental costs of bamboo can be reduced substantially by having production and processing areas located such that overseas transportation of bamboo products is not necessary.

“It has been estimated that the production of bamboo flooring, which is the same process for laminated bamboo planks that are used in other applications, consumes approximately 14,220 BTUs (15 MJ) per ton of bamboo produced. An additional 1.5 million BTUs (1645 MJ) per ton is expended to ship the finished product the equivalent of 500 miles” (Reiner, 2007, p.6). Clearly transportation is the main cause of environmental impact with regard to bamboo as a construction material.

4.4.3 Construction

Bamboo is a very lightweight material and can be assembled easily by hand. Therefore, there is no environmental impact from the construction of bamboo components and consequently no energy consumed during the construction phase.

4.4.4 Use

Most bamboo used in exterior applications, if properly coated for weather resistance, can last up to 15 years before it needs to be replaced. Fortunately, bamboo is a rapidly growing plant and since it is harvested on a 5 to 6 year rotation, the material in place can last up to and beyond 3 cycles of growing. The use of bamboo in exterior applications

implies the need for occasional replacement and maintenance, and should be written into the operating and maintenance budget as imminent.

4.4.5 Demolition and Recycling

“Bamboos can be regarded as recyclable material since their products can be incinerated or digested in sewage” (Asif, 2009, p.53). However, when laminated and pressed into planks or flooring, the issue becomes more complicated. This type of building demolition waste is usually handled in the same manner as plywood. Most treated plywood, and similarly laminated bamboo, is relegated to a landfill after it is removed from a building. “An alternative to the disposal of preservative-treated wood products is recycling the material into other products” (Demkin, 1998, MAT 06118 p.23). CCA-treated wood has been used to produce fiberboard and a wood-Portland cement composite. Treated bamboo could be used in a similar fashion. However, there will likely not be significant commercial utilization of this approach for some time – at least until the need arises when bamboo products, which are relatively new to the market, finally make it to the demolition and waste stream.

4.4.6 Conclusion

“Anticipated future demand for bamboo products has raised concern about overexploitation of natural bamboo groves, which currently supply much of the world’s bamboo” (Calkins, 2009, p.427). Therefore, future demand should be met by commercial bamboo plantations that are well managed and minimize impact on naturally occurring plant communities. In terms of source material location, India, Colombia, Brazil and China have the most natural bamboo stands and India currently has the most plantations. “More globally widespread bamboo cultivation would ensure that supplies are closer to where they are used to reduce the effects associated with overseas transportation of the material” (Calkins, 2009, p.427).

There is concern that some rapidly renewable products such as bamboo are not available regionally or are exotic. Bamboo is not commonly associated with forests in the United States. However, “many of the rapidly renewable products such as bamboo can be grown and produced within various regions of the United States” (Haselbach, 2010, p.223). Bamboo, to be truly sustainable, should be grown locally or at least within the United States

to make it less intrusive on the environment. “In the last decade, bamboo horticulturalists have begun to grow successfully a number of warm temperate and subtropical woody bamboos in the United States (principally in California and Florida), Europe and Japan” (Judziewicz, 1999, p.106). If successful in establishing plantations in the United States, the sustainability of bamboo will be such that it could render many wood products obsolete.

4.6 Life Span

The materials that have been selected for the Cheyenne and Arapaho Tribal College have, for the most part, high embodied energy due to intense extraction and production methods. However, these materials are crucial to the sustainability of the building itself. Concrete provides incredible thermal properties and is the only material - among those of concrete, stone and brick – that is capable of being placed precisely where it is needed with ease. In addition, it is the most suitable material for use in Earth-integrated construction. The concrete to be specified for the project has a fly ash content of 70% to provide extra strength and durability, as well as an eco-friendly alternative to pure Portland cement concrete. In addition to fly ash content, the concrete will consist of Type III recycled aggregate which consists of 15% recycled coarse aggregate and 5% recycled fine aggregate as a replacement for virgin materials. All virgin aggregate is to be locally obtained. The first reason is rooted in ecological sustainability with short transport distances requiring less fuel. The second reason is to give the building a sense of place. Local Oklahoma aggregates and sands have the same reddish hue of the soil which will beautifully blend the building with the landscape.

The glass that will be specified for the project is double-paned, argon-filled, Low-E glass panels which maximize the transmission of light and heat energy into the interior and minimize the heat lost in the opposite direction. Other than requesting glass that is made from 100% recycled content, there are no other ways at this point to lower the embodied energy of this material. Glass is the only material that can assist in both the transport of light and heat into the interior of the building for passive solar functioning and day-lighting.

The steel for the project will be primarily used for reinforcing the concrete. Because direct steel making is not common in the United States, specifying steel produced from 100% recycled scrap is the only sustainable step that can be taken to reduce the embodied energy of this material. If, by the time the project is constructed direct steelmaking has

become more popular and is located within a reasonable distance, the specification will be changed. Currently, steel is the best method for reinforcing concrete and is therefore being used properly in this project.

The laminated bamboo panels in this project are being used in an exterior application, therefore off-gassing is not an issue. Despite this fact, formaldehyde-free glues will be specified. To eliminate transportation from Asia, where most bamboo is grown, and the impacts on the environment (which can make bamboo extremely unfriendly), the bamboo should be grown and processed in the United States in the proper growing climate.

These materials will include a tremendous amount of embodied energy. However, as will be proved, this is minimal compared to the energy that could be consumed by the building during its useful life. Over the 100-year lifespan of a building, 15% of the energy consumption of a building is embodied in the construction materials. A whopping 85% is the energy consumed to heat, cool, and light the building (see figure 7, Appendix A). A more sustainable building will actually have a higher percentage of the energy in its materials and a lower percentage will be reflected in operational consumption. The goal of the Cheyenne and Arapaho Tribal College design is for 100% of the energy consumed during its existence to reside in the materials and no fossil-fuel-derived energy be used for its operation. A comparison of energy consumption is necessary to prove that the materials do indeed contribute to efficiency in a full Life Cycle Analysis.

The Cheyenne and Arapaho Tribal College, as institutional buildings should be, is designed for a useful life of more than 100 years. In this section, three buildings will be presented to analyze performance. The first building to be analyzed, which will be used as a control, represents the same square footage, dimensions, number of floors, and materials as the design for the Tribal College. What makes a significant difference is that it will be analyzed as a traditional above-ground institutional building assumed to have four walls composed of 50% solid material and 50% glass; and a roof of standard design. The building will still encompass two wings; both oriented on a 45-degree angle as shown in the design, and will be presented as a standard double-loaded corridor.

The second building to be analyzed is the design for the Cheyenne and Arapaho Tribal College if it remains on-the-grid and is run using traditional energy sources. All solid

walls are Earth-sheltered and any exposed walls are constructed entirely of glass as the design shows.

The third building takes all of the design factors into account along with all of the passive systems noted in the Methods section. This includes not only the earth-sheltered solid walls and abundance of south-facing glass, but also the use of daylight for internal illumination, geothermal technology to heat and cool the building, and wind power for all electrical needs.

In each case, the entire embodied energy of the building after 100 years will be presented, along with the amount of energy that will be required to heat, cool, and light the structure. Unfortunately, future energy rates cannot be anticipated. Fuel oil, natural gas, propane, electricity and all other energy sources vary in price regularly. However, it is anticipated that energy costs will continue to rise annually. Therefore, current prices for energy in Oklahoma will be used and are current as of April, 2011. According to Oklahoma Electric Cooperative Inc., the commercial rates for electricity are \$0.0965 per kilowatt-hour for the first 2000, and \$0.05653 per kilowatt-hour after the first 2000. The rate for natural gas, according to Oklahoma Natural Gas, is \$5.453 per dekatherm which translates to \$0.5453 per therm (100,000 BTUs). The price of propane as of March 2011 is \$3.54 per gallon and fuel oil is \$3.54 per gallon. This information plus the data on the building's square footage, volume, insulation R-values, areas of solid walls, and areas of glass are input into a computer program developed by Laurent Hodges – a former Professor of Physics at Iowa State University (see Appendix E and F). This program estimates the heating load on the building, as well as the annual heating cost and amount of energy needed from heating equipment for one entire winter season. In addition to heating, lighting needs are calculated along with cooling needs for each building. All calculations take a 100-year lifespan into account. These calculations will prove that the design itself, as well as the passive and alternative methods for running the building (including the necessary materials to render passive methods effective), make it truly sustainable.

4.6.1 Standard Building

This design would require approximately 11,694 tons of concrete. Approximately 1.5% of the weight of concrete consists of steel reinforcing which equates to approximately 175 tons. The glass required for the building would be 91 tons based on double-glazing

which requires two panes per window. The weight of the bamboo panels required for the shading devices should amount to approximately 40 tons. The embodied energy for the main construction materials are listed and do not include transportation. The reason transport costs are being omitted is because the distances can and will vary depending on where they are produced. Suppliers or materials have not yet been determined for this construction project.

Standard Concrete	608,804 BTUs per ton	11,694 tons	7,119,262,656 BTUs
Glass	15,000,000 BTUs per ton	91 tons	1,365,000,000 BTUs
Steel	22,000,000 BTUs per ton	175 tons	3,850,000,000 BTUs
Bamboo	14,220 BTUs per ton	40 tons	568,800 BTUs

Total Square Footage 125,684 square feet

Total Volume 1,812,408 cubic feet

Internal Heat Gains 795,000,000 BTUs/yr 20% of need

Solar Heat Gains 1,226,600,000 BTUs/yr 30% of need

Auxiliary Heat Needed 2,044,600,000 BTUs/yr 50% of need

2,044,600,000,000 BTUs for 100 years

Annual Heating Bill: Natural Gas \$11,614

Propane \$87,856

Fuel Oil \$52,778

Cooling 465,246 kWh annually

1,587,485,952 BTUs annually

1,587,485,957,000 BTUs in 100 years

\$26,518 annual cooling bill

Lighting 1,651,260 kWh annually @ 16 hour days

5,634,332,206 BTUs annually

5,634,332,206,000 Aux BTUs for 100 years

\$94,122 annual lighting costs

Materials Embodied Energy 12,334,831,456 BTUs

Total Embodied Energy 9,266,418,163,000 BTUs lifetime

9.27 trillion BTUs

In a standard building, the total net energy includes 100 years of operation and the embodied energy of the materials. In this case, the total net embodied energy is 9.27 trillion BTUs which is the equivalent of 1,597,658 barrels of oil (1 barrel of oil = 5,800,000 BTUs according to the U.S. Department of Energy) to put the numbers in perspective.

4.6.2 The Cheyenne and Arapaho Tribal College Design

This calculation is based solely on the design of the Tribal College. This calculation does not include the use of the wind turbines for the generation of electricity or the use of geothermal heating and cooling. The calculations are based on the earth-sheltered nature of all solid walls, the green roof as opposed to a standard roof, and glass as the only exposed walls. Approximately 12,503 tons of high-fly-ash concrete, 65.8 tons of glass, 188 tons of reinforcing steel, and 40 tons of bamboo panels will be needed for the design. Approximately 35% of the lighting requirements will be met with day-lighting due to the abundance of glass in the design which relies on single-loaded corridors. In addition, the expanse of south-facing glass will allow for substantial passive solar heat gains thereby reducing the need for auxiliary heat inputs.

70% FA Concrete	221,833 BTUs per ton	12,503 tons	2,773,578,000 BTUs
Glass	15,000,000 BTUs per ton	65.8 tons	987,000,000 BTUs
Steel	22,000,000 BTUs per ton	188 tons	4,136,000,000 BTUs
Bamboo	14,220 BTUs per ton	40 tons	568,800 BTUs

Total Square Footage 125,712 square feet

Total Volume 1,813,500 cubic feet

Internal Heat Gains 795,000,000 BTUs/yr 33% of need

Solar Heat Gains 1,206,400,000 BTUs/yr 50% of need

Auxiliary Heat Needed 416,900,000 BTUs/yr 17% of need

416,900,000,000 Aux BTUs for 100 years

Annual Heating Bill: Natural Gas \$2,368

Propane \$17,913

Fuel Oil \$10,761

Cooling 113,198 kWh annually

386,247,554 BTUs annually

386,247,554,000 BTUs in 100 years

\$6,452 annual cooling bill

Lighting 1,101,424 kWh annually @ 16 hour days

3,758,214,161 BTUs annually

3,758,214,161,000 BTUs in 100 years

\$62,781 annual lighting bill

Materials Embodied Energy 7,897,146,800 BTUs

Total Embodied Energy 4,569,258,861,800 BTUs lifetime

4.57 trillion BTUs

1.7% of the total is materials

In the design for the Cheyenne and Arapaho Tribal College, simply taking passive systems and the design into account, there is a substantial reduction in overall net embodied energy after 100 years compared to a standard building of the same size and cardinal orientation. The total net embodied energy of this building is 4.57 trillion BTUs, the equivalent of 787,803 barrels of oil (to put things in perspective), a savings of almost 4.7 trillion BTUs of energy over the standard building (saving 809,827 barrels of oil energy equivalent). In addition, substantial savings can be seen in the annual heating and cooling costs. However, even passive buildings that use active systems to make up for the heating, cooling, and lighting gap are not truly efficient and still consume tremendous amounts of energy. LEED would credit this building for energy efficiency as there is over a 30% energy savings during its lifetime. Although the savings of 4.7 trillion BTUs over a 100-year period is more than enough to offset the energy embodied in the materials, a significant amount of energy is still required to run the building. There is a better way.

4.6.3 The Cheyenne and Arapaho Tribal College Vision

The final set of calculations shows the same efficiency that the design itself boasts in the example above. With the addition of the geothermal heating/cooling system and the wind turbines for all electrical needs, the amounts drop dramatically.

70% FA Concrete	221,833 BTUs per ton	12,503 tons	2,773,577,999 BTUs
Glass	15,000,000 BTUs per ton	65.8 tons	987,000,000 BTUs
Steel	22,000,000 BTUs per ton	188 tons	4,136,000,000 BTUs
Bamboo	14,220 BTUs per ton	40 tons	568,800 BTUs

Total Square Footage 125,712 square feet

Total Volume 1,813,500 cubic feet

Internal Heat Gains 795,000,000,000 BTUs 33% of need

Solar Heat Gains 1,300,000,000,000 BTUs 50% of need

Auxiliary Heat by Geothermal 586,000,000,000 BTUs 17% of need

Annual Heating Bill: Geothermal \$0

Cooling	No effect on net embodied energy
Lighting	No effect on net embodied energy
Materials Embodied Energy	12,334,831,456 BTUs
Total Embodied Energy	12,334,831,456 BTUs lifetime

With the addition of the geothermal system and the wind turbines to the design of the Cheyenne and Arapaho Tribal College, a net energy savings is realized as there is no expense for purchasing electricity to run the lights and cooling system, and no other fuels to heat the building. The only embodied energy left after 100 years is that of the materials used to construct the building (the equivalent of 2,109 barrels of oil). With the energy to heat, cool, and light the building being provided completely off-the-grid and sovereign from supplies of outside vendors, the total energy saved in running the building can be subtracted from the embodied energy in the materials. In this case, the Cheyenne and Arapaho Tribal College will have a “net negative” embodied energy of -4,556,924,030,344 BTUs or -4.56 trillion BTUs (enough to save over 785,600 barrels of oil).

Speculators have projected energy cost increases from very minimal to catastrophic. Some experts are of the belief that oil and other energy costs will remain low up to and past 2050 while others have predicted a doubling of energy costs every 10 years. Taking a middle-of-the-road approach and including heating, cooling and lighting, the savings is substantial. If energy costs double every 25 years, the Tribe will save over \$27 million in operating costs all due to a passive design and energy sovereignty.

With all of the systems that were introduced in Chapter 3 and with the aid of the important materials described in Chapter 4, the Cheyenne and Arapaho Tribal College could be certified with proper documentation at the Platinum Level – LEED’s highest award. For additional information, see Appendix D. CATC was rated based on LEED Version 2.2 which has recently been updated. The data in Appendix D still refers to the older version until an update can be made to the documentation for the proposed design.

In the case of the Cheyenne and Arapaho Tribal College, Dr. Henrietta Mann has expressed interest in certifying the building. Not for the prestige of the LEED plaque in the entry, but for what it symbolizes – the effort at being more environmentally conscious which

ties action to a belief system where Mother Earth is to be respected, preserved, and thanked for all she provides to The People.

With regard to Ed Mazria's Architecture 2030 Challenge, this design meets the "carbon neutral" goal for the year 2030 by requiring no fossil-fuel-generated heating, cooling, or power for its operation. However, the embodied energy of the materials does not fair quite as well. The goal of 50% reduction in embodied energy cannot be achieved when using materials such as steel, glass, and concrete, and yet these materials are crucial components in the ability to be carbon-neutral during the building's lifetime. What Mazria is missing in his challenge is that there are materials that are required in passive design, that also contribute to longevity, that make meeting both goals – carbon neutral for operation and 50% reduction in materials embodied energy – difficult if not impossible. However, as a great professor once said, "sometimes you need a tiny bit of brown to get a whole lot of green" (Block, 2011).

5 Community Contributions

5.1 Introduction

The Cheyenne and Arapaho Tribal College has the potential to make a significant impact on the community as a whole. Nonprofits such as CATC need to focus on brand-making because of the manner in which they acquire funding. Standard businesses are able to thrive based on strong product development and correct placement within the marketplace. Nonprofits, however, do not act in the realm of a free market. Their funding comes from individual and organizational donors, foundations, grants and tribal governments. Acquiring funding on a national level is extremely competitive. In addition to competing for funding with other nonprofits, tribal college also compete amongst themselves for students, funds, and for a share of federal grants. Therefore, that which differentiates a tribal college's curriculum, environment, economic development, or community initiatives will greatly increase the visibility and viability of a tribal college's image.

The Cheyenne and Arapaho Tribal College can be an economic development resource for the entire community. "By connecting their own resources with those of the community, community colleges (and tribal colleges) help to create a better, more secure future both for themselves and for their neighbors" (Kretzmann, 1993, p.227). By providing internship opportunities and building capacity for tribal enterprises and entrepreneurship, the opportunities available to its citizens increase while dependence on outside expertise for growth decreases. A curriculum that assists in creating and strengthening a variety of industries and firms within the community will create apprenticeship programs that can be developed between the college and the businesses. "Community colleges that have formed partnerships with other local institutions are in an excellent position to find work for their students and graduates in these institutions, thus linking the community college with the community" (Kretzmann, 1993, p.229). The Cheyenne and Arapaho Tribal College also contributes to the well-being of the Tribes through its Early Childhood Education Program.

5.2 Potential Majors

The Cheyenne and Arapaho Tribal College administration has communicated the desire to add to their current degree offerings as they continue to expand, and as they seek accreditation. These include expansion of the Early Childhood Education and the addition

of Eco-Science and Agriculture, Niche Business Management, and Nursing and Health Services which are all majors that have immediate application to the well-being of tribal members.

Many college students at CATC will have family obligations as parents, grandparents, sons, daughters, aunts and uncles. The design of the campus includes housing for families and extended families, as well as single students needing daycare. It is crucial that families be considered in the overall educational model. In design, this translates to housing that will accommodate the students and their immediate (and occasionally extended) family members as well as increased importance of providing additional support services like daycare.

As Oveta Lira, the assistant to the CATC registrar said, “the one thing we need more than anything else right now is a daycare.” For CATC students and the community in general, there is a lack of affordable childcare and early childhood educational facilities. The Early Childhood Education major could provide opportunities for students to attend classes while their children have a safe, educational, culturally appropriate place to learn and laugh. As the children are cared for, students in the program can learn and interact with the children in their educational community to forge bonds that instill trust and community enrichment within the CATC family and the greater community. This is currently provided at the Head Start facility in Clinton, Oklahoma, but it is limited in terms of space and for internship opportunities. The facility in the design proposal for this thesis shows the Early Childhood Education wing of the building doubling as a daycare. This dual-purpose facility will allow students to learn in two ways: by providing a safe place for their children while they learn, and educational opportunities for students in the ECE major to participate in a hands-on environment. The long-term goal is for the ECE facility at CATC to be open to the community as well. This dual purpose can lead to a threefold benefit. First, students with children have time to learn, yet their children are nearby which allows for family interaction during the day. Second, it provides daycare for the community at a reduced cost, which will still be an income generator for the college but a relief to the community. Third, the children will receive substantial educational benefits which will aid in success in their future years.

Eco-Science and Agriculture is a degree program that contains several possible concentrations, as well as the ability to teach sustainability practices that are crucial in

contemporary society. The design of the entire campus is based on sustainability and will serve as a teaching and learning tool for this degree program. Concentrations such as bio-renewables, green energy, sustainable hydrology, range management, native “heirloom” agriculture, food sovereignty, and sustainable building technology are some possibilities. These concentrations have an opportunity to transform the Cheyenne and Arapaho community through environmental initiatives related to ecology and agriculture. Additionally, the building itself as well as this major will reflect a branding commitment through its green infrastructure, helping to create jobs in the area of sustainability and green initiatives. The passive qualities of the building, along with the environmentally sustainable systems such as the “Living Machine,” geothermal systems, and wind power can serve as teaching tools and learning tools as the very systems that run the campus are studied and maintained by the students. By standing at the precipice of eco-science and emerging sustainable trends and innovations, the students graduating under this major have the opportunity to position the Tribal community at the forefront of sustainability and can serve as a model for sustainable development and building technology. The Cheyenne and Arapaho Tribal College should be synonymous with sustainability in a way that allows the Tribe to be consultants in sustainable practices. Then, as leaders in environmental and cultural sustainability, the Cheyenne and Arapaho can lead the rest of Oklahoma and possibly the nation into an era of sustainable practices.

Niche Business Management can provide general business administration knowledge to the students with a focus on niches that can greatly impact the community, based upon need. In fact, as the needs of the community change, the niche specialties are expected to evolve and change over time. For the current situation, niche specialties such as co-op management, casino management, community management, tribal government administration, and agricultural management are just a few that are needed in the community at large. Should the tribe venture forth with a hotel and resort addition to the casino, a hotel and restaurant management niche could be created to facilitate the transition from just gaming to full resort management. It is CATC’s goal to not only produce good workers, but to produce innovative, articulate, entrepreneurs that create jobs and opportunities for other community members and assist in cycling money through the tribal business system rather than losing it to mainstream businesses. As business, industry, and tribal government needs evolve and change, the program should also evolve in sync to

provide competent graduates that are ready to tackle these new arenas within the community.

Currently, the Indian Health Services (IHS) facility is located in Clinton, Oklahoma which is 15 miles from Weatherford. Although the clinic provides basic healthcare and other specialized programs to assist with the general well-being of the community, it is being administered by the federal government based on the western model of healthcare. The Health Service degree could have specific niches of emphasis including nursing and healthcare, counseling, and nutrition. Graduates will be qualified to pursue their Bachelors of Science in Nursing, nutrition, or psychology at any four-year institution. Staffing the IHS clinic with Native professionals will increase the level of comfort for patients, as well as provide the opportunity for healthcare to be administered with greater sensitivity to culture and tradition. According to tribal members present at the planning meetings for the design of the campus, Native people are less likely to seek preventative care. In addition, IHS facilities are infamous for being understaffed, making response to urgent care difficult. Knowing that they are in the care of other Native community members might increase these visits (as has been shown in other situations, as in African American health care in the Southern United States. This reinforces sovereignty as the tribe exercises self-determination in dealing with health issues, nutrition issues, and substance abuse issues from their own worldview. Instead of these issues being “their” problem, with Native health practitioners and administrators, it becomes “our” issues and cared for in “our” ways. Hopefully with Tribal members deciding how to treat patients and how best to spend the IHS funding, the health of the community will continue to improve which can contribute to greater prosperity and community development.

The number of possible majors is endless at the Cheyenne and Arapaho Tribal College. The programs offered by the college should focus on three major goals: brand recognition, community needs, and innovation. The Cheyenne and Arapaho Tribal College – and possibly someday the Cheyenne and Arapaho Tribal University – should focus on offering programs and experiences that are not only desirable, but not offered by any other institution. They need the ability to draw from all communities and attract students seeking a unique and cultural experience in their education. In addition to this, they should focus on their own community’s immediate needs. Not only in degrees, but in continuing education courses and certificate programs that reach out to the community in ways that benefit the

Tribe. This could mean “essential training in a wide variety of practical skills (that) can be offered to certain ‘marginalized’ groups who might otherwise be excluded from classes” (Kretzmann, 1993, p.228). Finally, the programs should be innovative and on the forefront of progress and developments that will be beneficial not only to their immediate community, but to the entire nation and to Mother Earth. The buildings that have been proposed will not only provide the infrastructure needed to facilitate learning, but will themselves be studied, duplicated, and improved upon to thrust the Cheyenne and Arapaho ahead both economically and as leaders in the environmental community.

5.3 The Building

The Cheyenne and Arapaho Tribal College will not only bring progress to the community with regard to educational opportunities but also fuel economic development for the Nations (or Tribe of your choice) based on its existence. With a design as sustainable as the one proposed, the Tribe has the ability to be leaders at the forefront of sustainability. The building, through its passive design and systems, will serve as a model of sustainability for both Indigenous tribal development and mainstream building projects. The primary purpose of the proposed academic building is to house the facilities needed for students to study and obtain their degrees. In addition, the building serves as a learning and teaching tool for students, members of the tribal community, as well as outside visitors wishing to gain knowledge about fully sustainable and self-supporting building projects. The intent is to inform students about living in a sustainable way and to attract anyone in the larger community who wishes to understand how the campus works as a system to remain off the grid.

5.3.1 Sustainability Initiatives

Many colleges and universities are creating “green initiatives” to be more sustainable. These schools are working with existing infrastructure in an effort to reduce the impact of daily operations on the environment. As a mainstream college example, Iowa State University kicked off an initiative called “Live Green!” According to the Iowa State website (www.livegreen.iastate.edu), “‘Live Green!’ is Iowa State University's campus-wide sustainability initiative encouraging all faculty, staff, and students to be fully committed to and engaged in making our campus, its operations, and initiatives as ‘green’ as possible.” This initiative was declared by President Geoffroy in 2008 and presented two challenges to

the people on campus, “to be a leader in sustainability among land grant universities (and to recognize that the involvement and dedication of every member of the Iowa State University community is critical to achieving this goal” (www.livegreen.iastate.edu). The initiative points to recycling, energy conservation, and composting food waste as things that can be done to commit to the initiative. This initiative works with existing facilities that are not environmentally benign and focuses on reducing the impact as much as possible given the infrastructure currently in place.

Haskell Indian Nations University located in Lawrence, Kansas, as a Native example, offers a Bachelor of Science degree in Environmental Science. According to their website (www.haskell.edu), “the environmental science program is designed to provide students with a broad background in math and science as they pertain to environmental issues. Graduates of the program will be able to contribute to the environmental stewardship and sustainability of American Indian and Alaska Native communities, including interfacing with tribal and federal environmental programs.” Students at Haskell are at the forefront of studying environmental science and ways to reduce or eliminate environmental impacts, again in a campus of existing infrastructure. For Haskell, their approach is a “do as we say, not as we do” approach as they are studying within buildings that are not environmentally benign. Therefore, they cannot use their campus and its facilities to support this learning and teaching in an experiential way. Still, focus on environmental issues in Tribal Colleges is a significant step toward sustainability.

At the Cheyenne and Arapaho Tribal College, students will not only be studying about sustainability, they will be living it. In addition to the proposed academic building, all of the proposed student residences that will be added to the college campus will use the same passive and active systems for heating, cooling, and lighting. Therefore, students will be educated in an orientation upon moving onto campus in buildings that help instruct them in the management of passive solar heating and cooling control, as well as the sources of power and water management throughout campus. This is in addition to information on recycling, energy conservation and composting that many post-secondary institutions are implementing. The advantage of living and studying in sustainable buildings is the reinforcement it provides to what the students are learning. Students learn about what is possible when it comes to sustainability in their courses and then see the proof that it works on a continuous basis.

The value this brings to the Tribe is twofold. First, there is value added in the amount of money that is not spent on heating, cooling, lighting, and waste-water management that can be diverted to other Tribal economic endeavors. Second, the campus will provide proof that sustainability is possible and that it truly works on both small and large scale sites. Additionally, the Cheyenne and Arapaho Tribe will be at the forefront of sustainability with the proposed Tribal College design – which can propel them into the role of consultant to the larger population. Hopefully, with the help of the Cheyenne and Arapaho, other Indigenous tribes as well as mainstream society will take notice and accelerate their sustainability initiatives based on the success of the CATC campus.

5.3.2 A Community Construction Project

One of the possibilities surrounding the proposed Cheyenne and Arapaho Tribal College is to involve, to the extent possible, the greater community in the construction of the campus. To truly build community pride, involvement and a sense of ownership are recommended. For Tribal members to feel that CATC belongs to the community – like it is “their” college – each community member should feel as if the college is relevant to them, whether or not they are a student. It only takes a handful of experts in construction to direct the construction of any building. From there, it takes willing workers to carry out the instructions of the experts. In the building of CATC, it is intended that as many tribal members be involved in the construction process as possible. Participation in its construction, whether as a paid Native construction firm or worker, or as a volunteer, tends to bring pride of ownership – to feel as if one has played a part, however small, in the larger community “good” is a key component to the lasting desire to see the college flourish.

5.3.3 A Community Employer

The Cheyenne and Arapaho Tribal College has the potential to provide many jobs to members of the community. Although this includes faculty and administrative positions, support and staff positions must not be overlooked. These support positions include maintenance and janitorial positions, transportation, food service, landscape, and other vital roles to keep the campus functioning properly. In addition, the tribal college should employ students which not only offers tuition relief, but can contribute to their education. “Community (and tribal) colleges are often able to provide jobs (as well as job training) for residents of the community. This means that many students are able to extend their

education by working part-time for the community college where they are currently being trained” (Kretzmann, 1993, p.228). The existence of CATC can lead to many jobs for the surrounding community. “Tribal college will need to model business development through tribal-college-owned businesses, through business incubators, through technology investment and through continued partnerships with national, regional and tribal enterprise organizations” (Crazybull, 2009, p.215). As the college grows from a hand-full of students to several hundred, the opportunity for entrepreneurs to create businesses and services that benefit the students should increase which will also lead to greater employment and economic development for the community.

5.4 Conclusion

The Cheyenne and Arapaho Tribal College can contribute to tribal self-sufficiency through the preparation of students to launch community development and economic ventures. Dollars that are earned by the Tribe and spent within the Tribe at local businesses owned by Tribal members, stay within the Tribe rather than going to increase the economic well-being of mainstream companies such as Walmart. “Economic development on (Cheyenne and Arapaho) lands is likely to occur only where Native nations are calling the shots—that is, where they are exercising jurisdictional power over their own lands, institutions, and affairs and are able to make their own choices about development strategies and outcomes. Where outsiders call the shots, accountability disappears, community engagement disappears, and development fails (Cornell and Kalt 1992, 1998, 2007; Krepps and Caves 1994). CATC can contribute greatly to tribal self-determination, which “is essential to sustainable development” (p.6). As students learn business skills and creative problem-solving, ownership of businesses by Tribal members grows, and money is both earned and spent within the Tribe, this self-determination can be realized and counted upon to breed success.

The Cheyenne and Arapaho have come a long way with self-determination and are poised to increase community development for their tribe. The contribution of the Tribal College through three specific areas – food independence, non-gaming development at their casino, and sustainability initiatives that will make them consultants in the new green revolution, can increase Tribal sovereignty. More can be done to bridge the gap of inequality that exists between rural and urban Oklahoma. As Enrique Penalosa (2007),

former mayor of Bogota Colombia so correctly states “inequality permeates everything around us so pervasively that it is difficult to differentiate between what is inevitable and that which could be altered” (p.310). The Cheyenne and Arapaho have realized this inequality and are making great strides in an effort to bridge the gap. These efforts include an emphasis on education with their Head Start Program and the Cheyenne and Arapaho Tribal College, both of which are vital in the advancement of their people; and an emphasis on sustainability and taking the stress off of the Earth’s ecosystems.

6 Conclusion

The Cheyenne and Arapaho have been through an ordeal - one that covers many thousands of miles and many hundreds of years. Enduring migration and relocation, attempts at assimilation and extermination, they managed to hold on to as much culture and tradition as possible. It is clear that the policies of the white man have both succeeded and failed. They succeeded to the extent that Native American communities are not as sovereign in actuality as they are purported to be in servants of the United States Governmental treaties and policy. They have become the poorest socio-economic group on the continent and their educational attainment and access to opportunities are limited. The Cheyenne and Arapaho Tribal College has been established to change these circumstances – to assist The People in reaching goals of both cultural and personal fulfillment through a culturally rich education that melds the best of tribal knowledge with contemporary goals.

The design for the Cheyenne and Arapaho Tribal College brings sustainable and innovative architecture not only to the region of Western Oklahoma, but to the Cheyenne and Arapaho people. It is a design full of promise for the future, not only for the tribe but for ailing Mother Earth. She is not well. Humans, in spite of indigenous knowledge of the cyclical nature of the Earth, have made her deathly ill in the name of progress. The design is a model of alleviation, where the pressures of human existence and prosperity are nearly non-existent. It responds to the area, its climate and its people by taking into account the tribe's rich cultures, the unpredictable climate of Oklahoma, and the desire to be fully sustainable by incorporating building design and orientation, passive energy strategies, building mechanical systems and a major focus on the building materials that are appropriate culturally and ecologically, into a recipe for designing and constructing a truly sustainable work of architecture. This has been done. The only task to be completed is the construction of the campus so that The People can once again gather and learn and hope.

Acknowledgements

I would like to thank the faculty at the College of Design at Iowa State University for accepting me into their program, both undergraduate and graduate, which has allowed me the freedom to explore my passion. As a design student, it is important to have creative freedom. Not only was this apparent in studio design work, but in my ability to design my own degree program as I narrowed my goals for my thesis. After five years of endless hours in studio and one year of intense studying for my master's degree, I have finally reached the end. Thank you for the opportunity to further my education – on my terms.

This is a special thank you to David Block, my major professor, for keeping after me and maintaining that fire that I sat upon every day throughout my education. You have made me all the more passionate about architecture, which is a sacred gift that you possess. There are teachers that we barely remember days after the semester is over and then there are those that we look back upon with fond memories. The final category is those professors and teachers that have such a profound effect on me that they become a part of who I am. You have been with me from the beginning of my 6 years and I can say without a doubt that I will carry you and your teachings with me for the rest of my life. Thank you.

I would like to thank Lynn Paxson, who has kept her door open, sometimes at all hours, to assist in any way she can. The Cheyenne and Arapaho Tribal College Project would not have become a reality without you. I have truly appreciated your guidance and wisdom over the years. Thank you for keeping me grounded and I am glad that I could return the favor once-in-awhile.

I would like to thank the rest of my committee, Kristie Franz and Cornelia Flora, for their patience in receiving something – anything - to read. Having only one year to complete a thesis, I appreciate being able to work up to the last minute. I am grateful that both of you took the time to read and comment on my work.

I would like to thank my parents, Larry and Barb Gallagher for never losing faith that I would one day find my niche in life. I am pursuing something that I am passionate about, and it is truly a gift to me that you express such unending pride in my success. You have,

through your love and devotion to me and each other, inspired me to be the best I can be at whatever I do and to touch the lives of as many people as I can. Thank you.

I would like to thank The Cheyenne and Arapaho Tribes for their gracious hospitality and teachings during my educational journey. The perseverance of culture, tradition, and spirit are an inspiration and a reminder to never give up who I am and what I believe to be true. Without the efforts of the Cheyenne and Arapaho Tribal College, I would not have been propelled to create what has become the defining design of my education. I will be standing by to help make your dreams and mine come true. I would also like to thank some special members of the Cheyenne and Arapaho Tribe, as well as other close members of the community:

Dr. Henrietta Mann, President of the Cheyenne and Arapaho Tribal College

Gail Wilcox

Chief Lawrence Hart

Oveta Whiteshirt Lira

Janice Prairie Chief Boswell

Alden Whiteman

Rupert Nowlan

Nathan Hart

Dr. Les Price

Minoma Littlehawk Nixon

Pauline Harjo

Kathryn Harrison, Richard (Dick) Zahm, and Joel Shockley, Washita Battlefield

To all of the Cheyenne and Arapaho, I say “Hah-ho;” “Néá'eše” and Thank You.

Appendix A

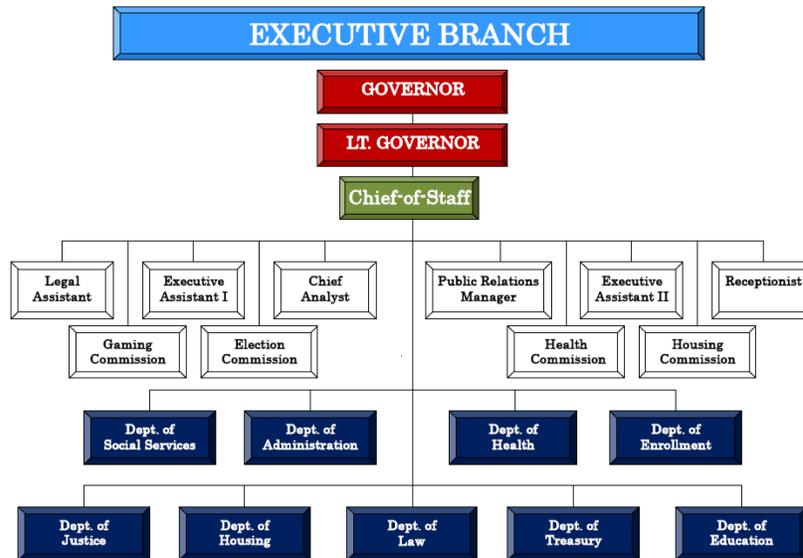


Figure 1 (above)

Image obtained from the 2009 Base Report, provided by the Cheyenne and Arapaho Tribal College.

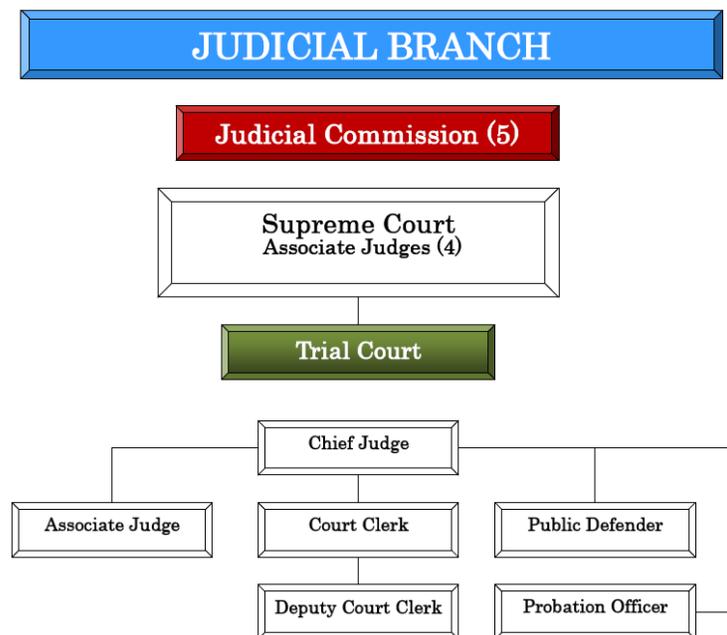


Figure 2 (above)

Image obtained from the 2009 Base Report, provided by the Cheyenne and Arapaho Tribal College.

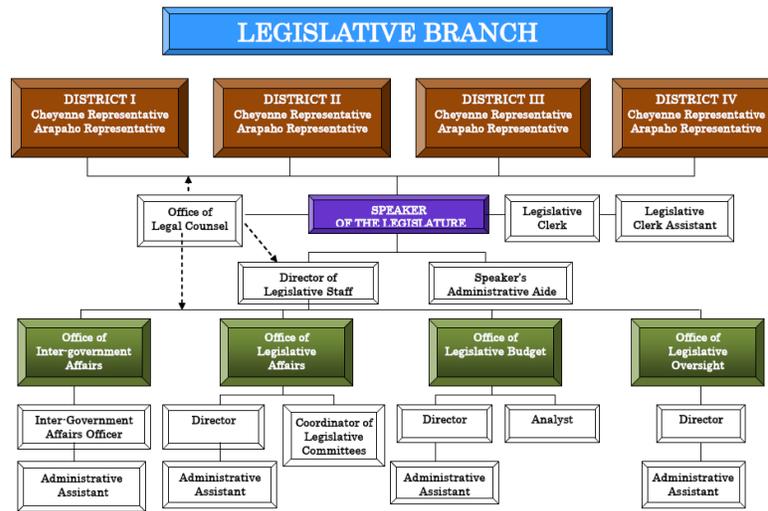


Figure 3 (above)

Image obtained from the 2009 Base Report, provided by the Cheyenne and Arapaho Tribal College.



Figure 4 (above)

The Cheyenne and Arapaho College Logo was designed by Chief Harvey Pratt of Guthrie, Oklahoma in 2006 and adopted by the CATC Board of Regents in the same year. The outer circle represents the circle of life and the continuing education of the Cheyenne and Arapaho through tradition. The cardinal points are reflected on the outer circle. The inner circle is the completion by the two tribes making one union, but two distinct tribes in their individuality. The upper half of the inner circle is the design of the “Blue Cloud People”, the Arapahos. The bottom half is the design for the Cheyenne, “The Striped Arrow People”. This is also reflected in the hand with the stripes on the fingers.

Image and logo description courtesy of the Cheyenne and Arapaho Tribal College at: <http://www.swosu.edu/catc/index.asp>

Appendix B

The Cheyenne and Arapaho Tribal College Current Degree Programs (Information current as of April 2011)

Associate in Science Degree General Studies

Communication	6 hours	CAENG 1113 CAENG 1213	English Composition I (required) English Composition II (required)
Mathematics	3 hours	CAMTH 1513 CAMTH 1143	College Algebra OR Math Concepts OR Higher Numbered Course
Computer Science	3 hours	CACMS 1023	Computers and Info Access (required)
Behavioral, Social & Cultural Science	6-7 hours	CAPSY 1003 CACHY 2004 CAARP CASOC 1003 CAHLW 1133	General Psychology (required) (Tribe) Language I (required) Introduction to Sociology Wellness Concepts and Exercise Applications
Natural Sciences	8 hours	CABIL 1004 CASI 1514 CAAST 1904 CACHM 1004 CAGOL 1934	Biological Concepts (required) Concepts of Physical Science Astronomy General Chemistry Physical Geology
Humanities & Fine Arts	6 hours	CAART 1223 CALIT 2413 CAMUS 1013 CAPHI 1453 CACOM 1313	Art Survey Intro to Literature Intro to Music Intro to Philosophy Intro to Public Speaking
History & Political Sciences	6 hours	CAHIS 1063 CAPLS 1103	U.S. History (required) American Government & Politics (required)
Economic & International Studies	6 hours	CAHIS 1033 CAGOG 1103 CAECN 2263 CAECN 2363	World History (required) World Cultural Geography Introduction to Macroeconomics OR Introduction to Microeconomics
Program Requirements	15-16 Hours	CAGEN	Elective Courses to Complete Degree

Total Hours 59-61

Associate in Science American Indian Studies

Communication	6 hours	CAENG 1113 CAENG 1213	English Composition I (required) English Composition II (required)
Mathematics	3 hours	CAMTH 1513 CAMTH 1503	College Algebra OR Algebra for Elementary Teachers
Computer Science	3 hours	CACMS 1023	Computers and Info Access (required)
Behavioral, Social & Cultural Science	7 hours	CAPSY 1003 CACHY 1204 CAARP 1254	General Psychology (required) Cheyenne Language I (required) OR Arapaho Language I OR
Natural Sciences	8 hours	CABIL 1004 CASCI 1514 CAAST 1904 CACHM 1004 CAGOL 1934	Biological Concepts (required) Concepts of Physical Science Astronomy General Chemistry Physical Geology
Humanities & Fine Arts	6 hours	CAPHI 1513 CACOM 1313	Am Indian Belief Systems (required) Introduction to Public Speaking (required)
History & Political Sciences	6 hours	CAHIS 1063 CAPLS 1103	U.S. History (required) American Government & Politics (required)
Economic & Tribal Studies	6 hours	CATRA 2133 CATRS 2603	Tribal Government I (required) C&A History (required)
Program Requirements	19 Hours	CATRS 1111 CATRS 1402 CALIT 1553 CAHIS 2203 CAACG 1123 CAACG 2213 CAGEN 1001-4 CAGEN 1011-4 CACHY 1214 CAARP 1264 CAMUS 1563 CAART 2103 CAGEN 2001-4 CAGEN 2011-4 CAECN 2423 CATRS 2603 CABUS 1123	Introduction to American Indian Studies Cheyenne and Arapaho Constitution Literature of the American Indian American Indians Today Introduction to Accounting Principles of Accounting I Individual Study Seminar Topic Cheyenne Language II OR Arapaho Language II Music of the American Indian Art History of the Plains Indian Individual Study Seminar Topic Tribal Economics Cheyenne and Arapaho History Introduction to Business
Total Hours	64		

Associate of Science Degree in Tribal Administration

Communication	6 hours	CAENG 1113 CAENG 1213	English Composition I (required) English Composition II (required)
Mathematics	3 hours	CAMTH 1513 CAMTH 1143 Higher Numbered Course	College Algebra OR Math Concepts OR Higher Numbered Course
Computer Science	3 hours	CACMS 1023	Computers and Info Access (required)
Behavioral, Social & Cultural Science	7 hours	CAPSY 1003 CACHY 1204 CAARP 1254	General Psychology (required) Cheyenne Language I OR Arapaho Language I (required)
Natural Sciences	8 hours	CABIL 1004 CASCI 1514 CAAST 1904 CACHM 1004 CAGOL 1934	Biological Concepts (required) Concepts of Physical Science Astronomy General Chemistry Physical Geology
Humanities & Fine Arts	6 hours	CAPHI 1513 CACOM 1313	Am Indian Belief Systems (required) Introduction to Public Speaking (required)
History & Political Sciences	6 hours	CAHIS 1063 CAPLS 1103	U.S. History (required) American Government & Politics (required)
Economic & Tribal Studies	6 hours	CATRS 2133 CAECN 2363 CAECN 2263	Tribal Government I (required) Introduction to Microeconomics OR Introduction to Macroeconomics
Program Requirements	17 Hours	CAGEN 1001-4 CAGEN 1011-3 CAGEN 2001-3 CAGEN 2011-4 CATRA 2062 CATRA 2103 CATRA 2123 CAACG 2213 CATRA 2233 CABUS 2253 CAACG 2313 CATRA 2313 CATRA 2413 CATRA 2513 CATRA 2523	Individual Study Seminar Topic Individual Study Seminar Topic Internship (required) Budget Operations Introduction to Tribal Administration Principles of Accounting I (required) Tribal Government II Business Communications Principles of Accounting II Indian Self-Determination and Education Assistance Act, amended 1994 Indian Self-Determination Contract Administration I (required) Indian Self-Determination Contract Administration II OMB Circulars (Common Laws)
Total Hours	62		

Associate of Science Degree in gī' ssh gon ni h̄ hoo ssto'mo ssī ni vi 'ho' ☉
(Children's Teachers)

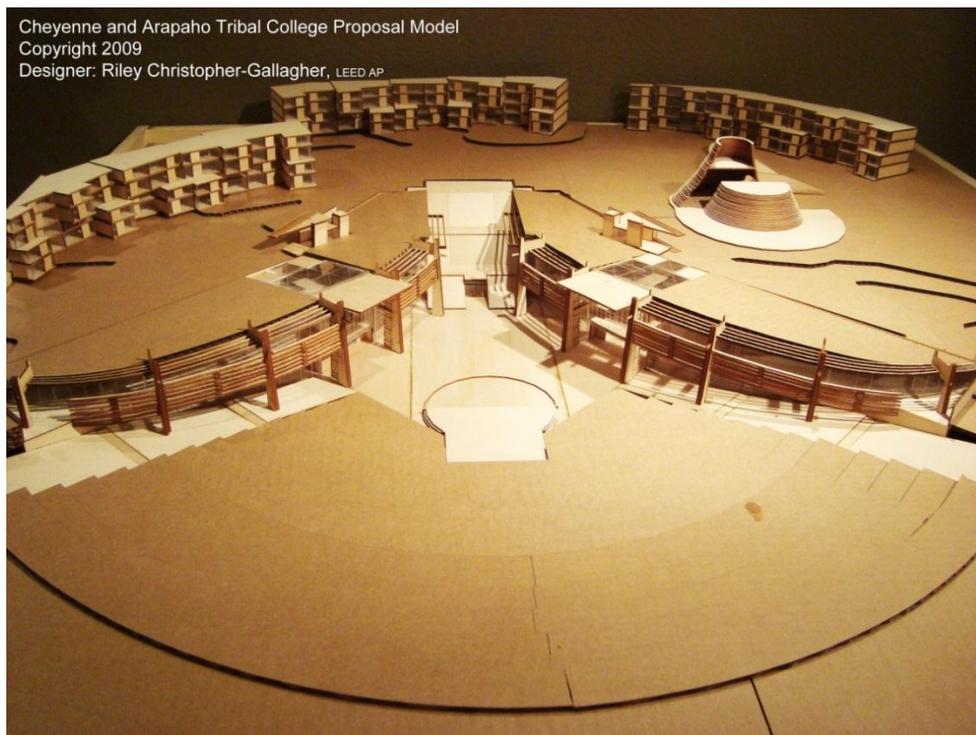
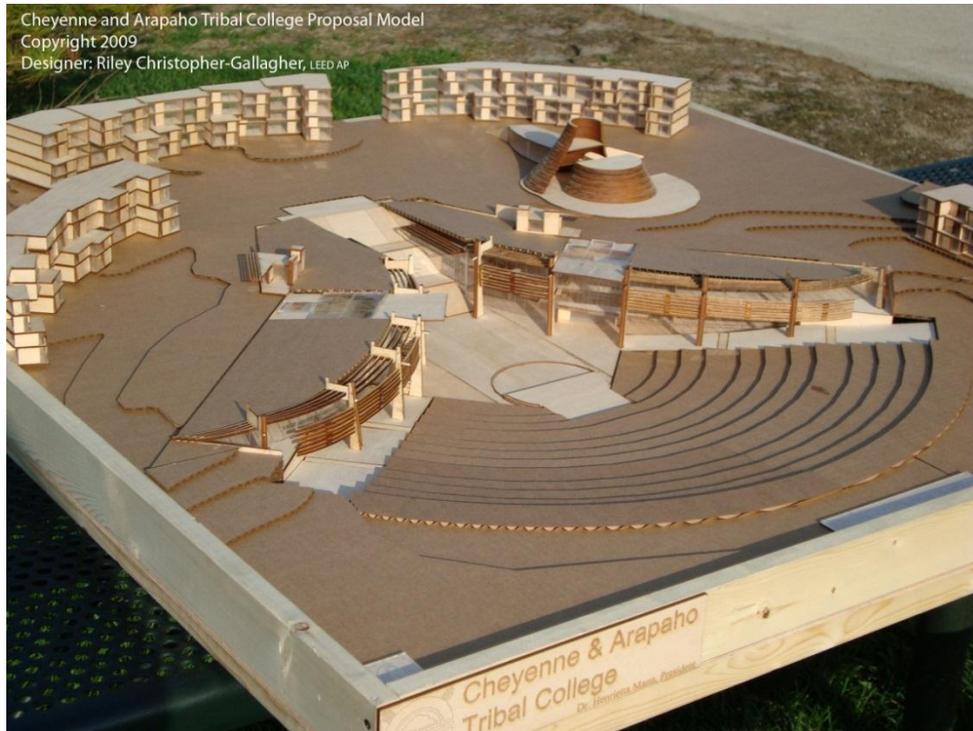
Communication	6 hours	CAENG 1113 CAENG 1213	English Composition I (required) English Composition II (required)
Mathematics	3 hours	CAMTH 1513 CAMTH 1503	College Algebra OR Algebra for Elementary Teachers
Computer Science	3 hours	CACMS 1023	Computers and Info Access (required)
Behavioral, Social & Cultural Science	7 hours	CAPSY 1003 CACHY 2004 CAARP 2004 CALNG	General Psychology (required) Cheyenne Language I (required) OR Arapaho Language I OR American Sign Language (4-6 hrs)
Natural Sciences	8 hours	CABIL 1004 CASCI 1514 CAAST 1904 CACHM 1004	Biological Concepts (required) Concepts of Physical Science Astronomy General Chemistry
Humanities & Fine Arts	6 hours	CAPHI 1513 CACOM 1313	Am Indian Belief Systems (required) Introduction to Public Speaking (required)
History & Political Sciences	6 hours	CAHIS 1063 CAPLS 1103	U.S. History (required) American Government & Politics (required)
Economic & Tribal Studies	6 hours	CATRS 2133 CATRS 2603	Tribal Government I (required) C&A History (required)
Program Requirements	19 Hours	CAMTH 1443 CAMTH 1433 CAMTH 2133 CAGEL 1934 CAHLW 1153 CALIT 2133	Structural Concepts in Mathematics Structural Concepts in Arithmetic Geometry for Elementary Teachers Physical Geology Nutrition Literature of the American Indian

Total Hours 64

Information on the degrees at the Cheyenne and Arapaho Tribal College downloaded from their website at <http://www.swosu.edu/catc/index.asp>

Appendix C

The Cheyenne and Arapaho Tribal College Design



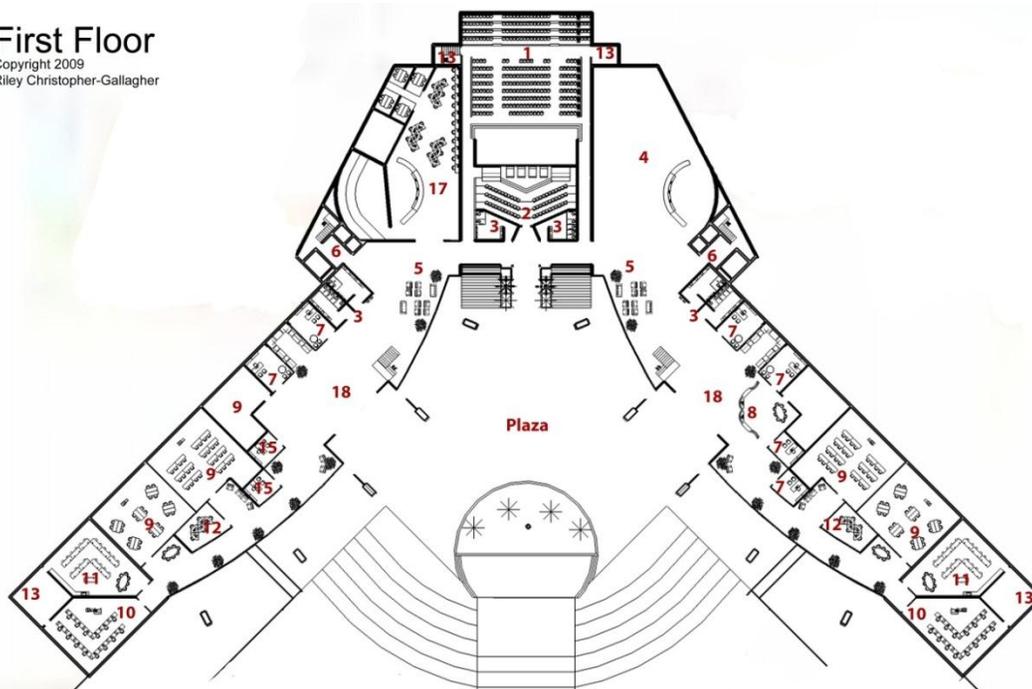


Floor Plan Codes

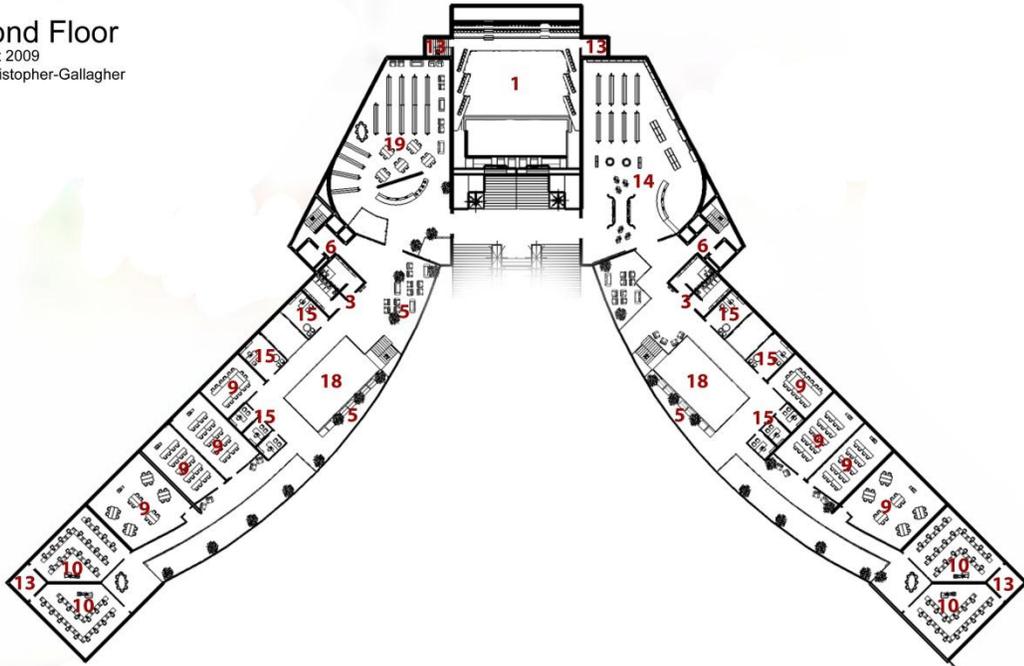
1. Auditorium
2. Small Auditorium
3. Restrooms
4. Commons & Cafe
5. Lounge Space
6. Elevator & Stairs
7. Administrative Offices
8. Student Assistance Desk
9. General Classroom
10. Computer-Based Classroom
11. Laboratory Classroom
12. Computer Lab
13. Emergency Exit
14. Bookstore and C-Store
15. Faculty Office
16. Early Childhood Education Center & Daycare
17. Media Center
18. Atrium
19. Library
20. Wellness Center
21. Nursing and Health Services School

First Floor

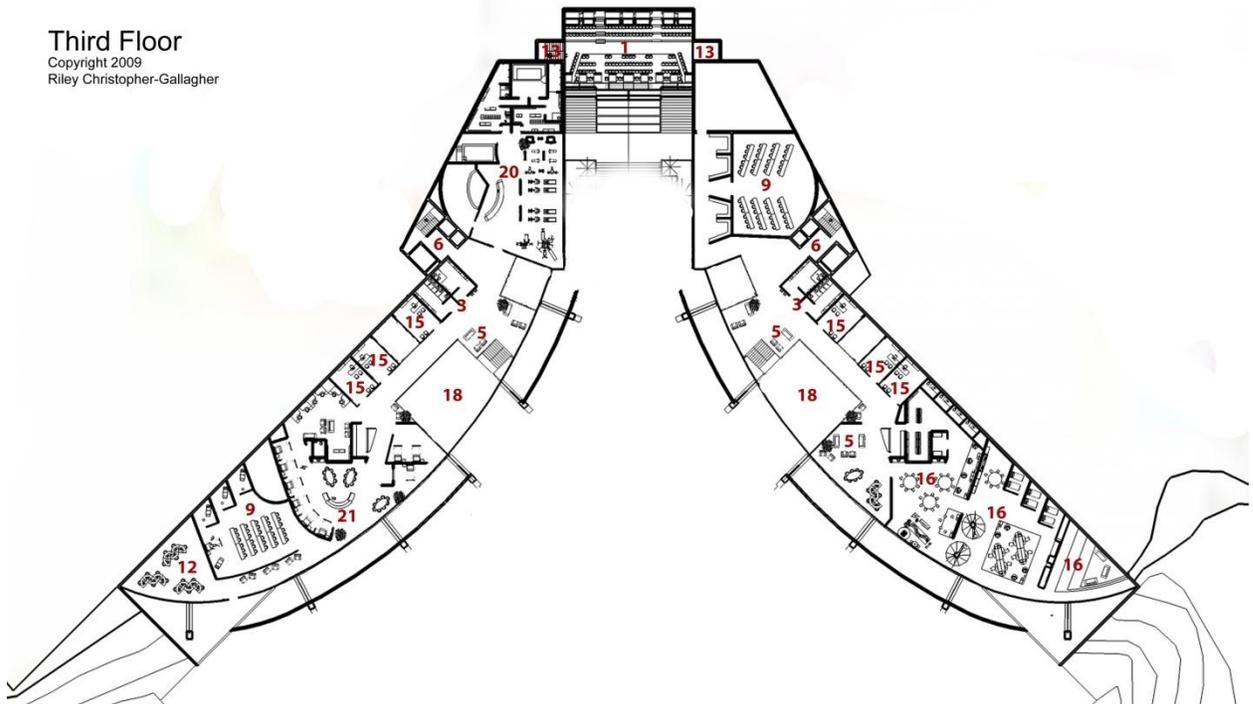
Copyright 2009
Riley Christopher-Gallagher



Second Floor
Copyright 2009
Riley Christopher-Gallagher



Third Floor
Copyright 2009
Riley Christopher-Gallagher





Appendix D

LEED Worksheet – Credits Possible for the Design Proposal



LEED for New Construction v 2.2 Registered Project Checklist

Project Name: Cheyenne and Arapahoe Tribal College

Project Address: Weatherford, OK

Yes	?	No			
61			Project Totals (Pre-Certification Estimates) 69 Points		
PLATINUM			Certified: 26-32 points	Silver: 33-38 points	Gold: 39-51 points Platinum: 52-69 points

Yes	?	No		
12			Sustainable Sites 14 Points	
0			Prereq 1	Construction Activity Pollution Prevention Required
1			Credit 1	Site Selection 1
1			Credit 2	Development Density & Community Connectivity 1
0			Credit 3	Brownfield Redevelopment 1
1			Credit 4.1	Alternative Transportation , Public Transportation 1
1			Credit 4.2	Alternative Transportation , Bicycle Storage & Changing Rooms 1
1			Credit 4.3	Alternative Transportation , Low-Emitting & Fuel Efficient Vehicles 1
1			Credit 4.4	Alternative Transportation , Parking Capacity 1
1			Credit 5.1	Site Development , Protect or Restore Habitat 1
1			Credit 5.2	Site Development , Maximize Open Space 1
1			Credit 6.1	Stormwater Design , Quantity Control 1
1			Credit 6.2	Stormwater Design , Quality Control 1
1			Credit 7.1	Heat Island Effect , Non-Roof 1
1			Credit 7.2	Heat Island Effect , Roof 1
1			Credit 8	Light Pollution Reduction 1

Yes	?	No		
5			Water Efficiency 5 Points	
1			Credit 1.1	Water Efficient Landscaping , Reduce by 50% 1
1			Credit 1.2	Water Efficient Landscaping , No Potable Use or No Irrigation 1
1			Credit 2	Innovative Wastewater Technologies 1
1			Credit 3.1	Water Use Reduction , 20% Reduction 1
1			Credit 3.2	Water Use Reduction , 30% Reduction 1





LEED for New Construction v 2.2 Registered Project Checklist

Yes	?	No			
17			Energy & Atmosphere		17 Points
Yes			Prereq 1	Fundamental Commissioning of the Building Energy Systems	Required
Yes			Prereq 1	Minimum Energy Performance	Required
Yes			Prereq 1	Fundamental Refrigerant Management	Required
<p>*Note for EAc1: All LEED for New Construction projects registered after June 26, 2007 are required to achieve at least two (2) points.</p>					
10			Credit 1	Optimize Energy Performance	1 to 10
			Credit 1.1	10.5% New Buildings / 3.5% Existing Building Renovations	1
			Credit 1.2	14% New Buildings / 7% Existing Building Renovations	2
			Credit 1.3	17.5% New Buildings / 10.5% Existing Building Renovations	3
			Credit 1.4	21% New Buildings / 14% Existing Building Renovations	4
			Credit 1.5	24.5% New Buildings / 17.5% Existing Building Renovations	5
			Credit 1.6	28% New Buildings / 21% Existing Building Renovations	6
			Credit 1.7	31.5% New Buildings / 24.5% Existing Building Renovations	7
			Credit 1.8	35% New Buildings / 28% Existing Building Renovations	8
			Credit 1.9	38.5% New Buildings / 31.5% Existing Building Renovations	9
			--> Credit 1.10	42% New Buildings / 35% Existing Building Renovations	10
3			Credit 2	On-Site Renewable Energy	1 to 3
			Credit 2.1	2.5% Renewable Energy	1
			Credit 2.2	7.5% Renewable Energy	2
			--> Credit 2.3	12.5% Renewable Energy	3
1			Credit 3	Enhanced Commissioning	1
1			Credit 4	Enhanced Refrigerant Management	1
1			Credit 5	Measurement & Verification	1
1			Credit 6	Green Power	1





LEED for New Construction v 2.2 Registered Project Checklist

Yes	?	No		
8			Materials & Resources	13 Points

Yes	?	No		
0			Prereq 1 Storage & Collection of Recyclables	Required
0			Credit 1.1 Building Reuse , Maintain 75% of Existing Walls, Floors & Roof	1
0			Credit 1.2 Building Reuse , Maintain 95% of Existing Walls, Floors & Roof	1
0			Credit 1.3 Building Reuse , Maintain 50% of Interior Non-Structural Elements	1
1			Credit 2.1 Construction Waste Management , Divert 50% from Disposal	1
1			Credit 2.2 Construction Waste Management , Divert 75% from Disposal	1
0			Credit 3.1 Materials Reuse , 5%	1
0			Credit 3.2 Materials Reuse , 10%	1
1			Credit 4.1 Recycled Content , 10% (post-consumer + 1/2 pre-consumer)	1
1			Credit 4.2 Recycled Content , 20% (post-consumer + 1/2 pre-consumer)	1
1			Credit 5.1 Regional Materials , 10% Extracted, Processed & Manufactured	1
1			Credit 5.2 Regional Materials , 20% Extracted, Processed & Manufactured	1
1			Credit 6 Rapidly Renewable Materials	1
1			Credit 7 Certified Wood	1

Yes	?	No		
14			Indoor Environmental Quality	15 Points

Yes	?	No		
Yes			Prereq 1 Minimum IAQ Performance	Required
Yes			Prereq 2 Environmental Tobacco Smoke (ETS) Control	Required
1			Credit 1 Outdoor Air Delivery Monitoring	1
1			Credit 2 Increased Ventilation	1
1			Credit 3.1 Construction IAQ Management Plan , During Construction	1
1			Credit 3.2 Construction IAQ Management Plan , Before Occupancy	1
1			Credit 4.1 Low-Emitting Materials , Adhesives & Sealants	1
1			Credit 4.2 Low-Emitting Materials , Paints & Coatings	1
1			Credit 4.3 Low-Emitting Materials , Carpet Systems	1
1			Credit 4.4 Low-Emitting Materials , Composite Wood & Agrifiber Products	1
1			Credit 5 Indoor Chemical & Pollutant Source Control	1
1			Credit 6.1 Controllability of Systems , Lighting	1
1			Credit 6.2 Controllability of Systems , Thermal Comfort	1
1			Credit 7.1 Thermal Comfort , Design	1
1			Credit 7.2 Thermal Comfort , Verification	1
1			Credit 8.1 Daylight & Views , Daylight 75% of Spaces	1
0			Credit 8.2 Daylight & Views , Views for 90% of Spaces	1



LEED for New Construction v 2.2 Registered Project Checklist

Yes	?	No		
5			Innovation & Design Process	5 Points
1			Credit 1.1 Innovation in Design: Geothermal Exchange with Rainwater Capture	1
1			Credit 1.2 Innovation in Design: Use of Living Machine for Wastewater	1
1			Credit 1.3 Innovation in Design: Only 17% Auxiliary Heating Input Needed	1
1			Credit 1.4 Innovation in Design: Earth-Integrated Design	1
1			Credit 2 LEED® Accredited Professional	1

The author, holding a professional designation as a LEED Accredited Professional, has used the LEED v 2.2 Registered Project Checklist and LEED Logo with the permissions of the USGBC as a privilege of his professional designation as a LEED AP. www.usgbc.org

Appendix E

Heating Energy Analysis of a Standard Building

ENERGY PERFORMANCE WORKSHEET FOR A BUILDING IN OKLAHOMA

Directions: Enter all information requested on screens 1 through 12 (screens are numbered at the bottom right). The numbers in the worksheet will recalculate automatically. Press key F10 to see a graph.

(C) Copyright 1985- 1994 by Laurent Hodges, P. O. Box 1238, Ames, Iowa 50014- 1238.

GENERAL INFORMATION ABOUT THE PROJECT

Enter below the name, address, and builder for the project.

PROJECT: Standard College Building
 ADDRESS: Weatherford, OK
 BUILDER: Riley Christopher - Gallagher, LEED AP

- 1-

3905 = HEATING DEGREE-DAYS AT PROJECT LOCATION

Enter approximate heating degree-days for the location of the project, using the numbers below as a guide.

6874 Ames	6671 Cedar Rapids	6482 Clinton
6200 Council Bluffs	6554 Des Moines	7375 Dubuque
7175 Fort Dodge	5587 Keokuk	7881 Mason City
6339 Ottumwa	6947 Sioux City	7537 Waterloo

GENERAL INFORMATION ABOUT THE HOUSE

125684 = TOTAL HEATED FLOOR AREA IN SQUARE FEET

Enter here the total heated floor area of the building in square feet. Count all levels, including the basement level if it is heated.

1,812,000 = INTERIOR VOLUME OF BUILDING IN CUBIC FEET

Enter here the interior volume of the building in cubic feet. This is the heated floor area times the average ceiling height. Count all heated spaces, including basement if it is heated.

- 2-

INFORMATION ABOUT WINDOWS

- 3 = TYPE OF WINDOWS. Enter the number corresponding to the main type of window used in the home:
- 1 for single-pane or ordinary double-pane windows
 - 2 for double-pane windows with night insulation
 - 3 for windows that are low-E or that have 3 or more panes.

On the next screen, use the manufacturer's U-value for the windows or estimate it from the following information:

- 1.13 for single-pane windows (1/4 inch thick)
- 0.55 for 1/8-inch double-pane windows, 1/4-inch air space
- 0.47 for 1/4-inch double-pane windows, 1/2-inch air space
- 0.44 for double-pane low-E windows, 1/4-inch air space
- 0.39 for 1/8-inch triple-pane windows, 1/4-inch air space
- 0.34 for 1/4-inch triple-pane windows, 1/2-inch air space

0.23 for Heat Mirror window (2 panes + H.M film)

- 3-

INFORMATION ABOUT WINDOWS

List the area, clear % (percentage of rough window area that consists of clear glass, usually 70-80 %), and U-value (using numbers on screen 4 as a guide) in the table below.

Area (sq. ft.)	Clear %	U	Description	
7566	90	0.30	South	Only what is on these 9 lines will be accepted.
7566	90	0.30	South	
7566	90	0.30	East	
7566	90	0.30	East	
7566	90	0.30	North	
7566	90	0.30	North	
6336	90	0.50	West	
			West	
			Skylights	

- 4-

INFORMATION ABOUT WALLS

Below, include information about the walls of the home. Include the opaque portions of the walls, but not the windows. The area should be the area above the conditioned space. Space is left to include a description of the different parts of the roof or ceiling if you have more than one part

Area (sq. ft.)	R	Description	
60528	30	Main Floor	Only what is on these 7 marked lines will be accepted.
0	29	Upper Floor	
0	15	Lower Floor	
0	5	Doors	

- 5-

INFORMATION ABOUT ROOF AND/ OR CEILING

Below, include information about the roof or ceiling of the home. Include only the opaque portions of the roof, not skylights. The area should be the area above the conditioned space. Space is left to include a description of the different parts of the roof or ceiling if you have more than one part

Area (sq. ft.)	R	Description	
46472	42	Ceiling - through insulation	Only what is on these
0	12	Ceiling - through insulation	

| 7 marked
| lines
| will be
| accepted.

- 6-

FLOORS OVER UNHEATED SPACES

Enter below the area and the R-value of any floors over unheated areas.

Area (sq. ft.)	R	
0	40	Enter 0's if you have no floors over unheated spaces

HEATED SLAB ON GRADE

Enter below the area and the R-value under any heated slab on grade.

Area (sq. ft.)	R	
0	0	Enter 0's if you have no heated slab on grade

- 7-

UNHEATED SLAB ON GRADE

Enter below the area and the R-value under any unheated slab on grade.

Area (sq. ft.)	R	
0	0	Enter 0's if you have no unheated slab on grade

CRAWL SPACE WALLS

Enter below the area and the R-value of the exterior walls of any crawl spaces below uninsulated floors.

Area (sq. ft.)	R	
0	0	Enter 0's if you have no such crawl space walls

- 8-

INFORMATION ABOUT BASEMENT WALLS

Area (sq. ft.)	R	M d-depth	Description
0	15	5	South Walls
0	15	3.25	East and North Walls
0	15	3.75	West Wall
0	0	0	

Enter above information about the basement walls of the building. In column A enter the area in square feet. In column B enter the R-value of the wall. In column C enter the depth (in feet) of the middle of the wall; for example, a wall extending from a depth of 0 feet to 7 feet would have a mid-depth of 3.5 feet. In column D, do not extend description past the last dash marks above and below.

This is limited to four lines of information.

- 9-

MISCELLANEOUS INPUT

- 1 = AIR CHANGES PER HOUR. Enter the estimated air infiltration rate in the home. For an energy-efficient home this is typically about 0.5 air changes per hour.
- 3750000 = AVERAGE DAILY TOTAL INTERNAL HEAT IN Btu. This number is not critical but has some effect on utility costs. A reasonable estimate is 25,000 times one more than the number of occupants of the home.
- 1 = AMOUNT OF THERMAL STORAGE. This is only important in passive solar homes. Enter the number corresponding to the amount of thermal storage in the building:
 - 1. Low amount
 - 2. Intermediate amount
 - 3. High amount

- 10-

INFORMATION ABOUT POSSIBLE HEATING SYSTEMS

The input numbers on this page are used only to determine the estimated utility costs for an average heating season. If you are using an electric heat pump or a gas furnace in the home, be sure to put in the correct value below.

- 2.00 = SCOP FOR ELECTRIC HEAT PUMP
Enter the seasonal COP (coefficient of performance) of the electric heat pump to be installed.
- 96 % = AFUE FOR GAS, PROPANE OR OIL-FIRED FURNACE
Enter the AFUE (Annual Fuel Utilization Efficiency) of the natural gas or propane or oil-fired furnace to be installed.

- 11-

ENERGY PRICES

Enter below the prices of energy for your locality. It is the price of the energy used as a heating fuel that is relevant.

PRICE OF ELECTRICITY:

9.7 cents per kWh for first 2000 kWh
 5.7 cents per kWh for next 2000 kWh
 0.0 cents per kWh above that

54.53 cents per therm (100,000 Btu) = PRICE OF NATURAL GAS

375 cents per gallon = PRICE OF PROPANE

354 cents per gallon = PRICE OF FUEL OIL

- 12-

SUMMARY OF COMPLIANCE WITH IOWA ENERGY CODE

Home Heating Index: 6.93 Btu/degree-day per square foot

Comparison of project with 1992 Model Energy Code requirements:

		CODE	PROJECT
Walls:	maximum U =	0.150	0.122
Roof/Ceiling:	maximum U =	0.036	0.081
Floors over unheated spaces:	maximum U =	0.050	0.025
Heated slab on grade:	minimum R =	5.5	0.000
Unheated slab on grade:	minimum R =	3.6	0.000
Basement wall:	maximum U =	0.101	0.000
Crawl space wall:	maximum U =	0.060	0.000

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December 1994 version of worksheet prepared by:

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This spreadsheet is intended to allow you to check if an Iowa home meets the component standards of the 1992 Model Code. It will also estimate the heat loss and utility costs for a typical Iowa single-family home or duplex with a basement. It works less well for bigger buildings or slab-on-grade homes, for which the heat loss depends on details of the foundation wall insulation that require a more sophisticated model, and cannot be accurately modeled in terms of Btu per degree-day.

 BUILDING HEAT LOSS ESTIMATE

EFFECTIVE
 SQ. FT. R VALUE Btu/DD



Walls,	60607	30.0	48422	Walls
ceilings,	46472	42.0	26555	Roof / ceiling
and	0	40.0	0	Floors over unheated spaces
floors	0	0.0	0	Heated slab on grade
	0	0.0	0	Unheated slab on grade
	0	0.0	0	Basement walls
	0	0.0	0	Crawl space walls
Windows	7566	3.3	54475	South windows
	15132	3.3	108950	East / West windows
	7566	3.3	54475	North windows
	6336	2.0	76032	Skylights
AIR INFILTRATION HEAT LOSS:			782784	Btu / degree-day
BUILDING HEAT LOSS COEFFICIENT:			1151694	Btu / degree-day
ESTIMATED HEATING LOAD:			3263134	Btu / hour at winter dry-bulb T

Abbreviations: Btu = British thermal units
DD = Fahrenheit heating degree-day
MBtu = Million Btu

THERMAL PERFORMANCE

ASSUMED AIR CHANGES PER HOUR:		1.00	air changes per hour	
BUILDING HEAT LOSS COEFFICIENT:		1151694	Btu / DD	
MAXIMUM HEATING SYSTEM LOAD:		3,263,134	Btu / hour	
	OCT	NOV	DEC	JAN
Heating degree-days	197	462	678	770
Gross heat loss (MBtu)	227.03	531.91	781.18	886.52
Internal heat (MBtu)	116.25	112.50	116.25	116.25
Net heat loss (MBtu)	110.78	419.41	664.93	770.27
Solar Gain (MBtu)	367.09	266.18	272.94	353.58
Solar Load Ratio (SLR)	3.314	0.635	0.410	0.459
Solar Heating Fraction	0.933	0.369	0.242	0.271
Useful solar (MBtu)	103.38	154.77	161.20	208.82
Auxiliary heat (MBtu)	7.39	264.64	503.73	561.45
	FEB	MAR	APR	TOTAL
Heating degree-days	638	528	257	3531
Gross heat loss (MBtu)	734.73	608.46	296.38	4066.21
Internal heat (MBtu)	105.00	116.25	112.50	795.00
Net heat loss (MBtu)	629.73	492.21	183.88	3271.21
Solar Gain (MBtu)	369.51	428.09	365.66	2423.05
Solar Load Ratio (SLR)	0.587	0.870	1.989	
Solar Heating Fraction	0.344	0.479	0.793	
Useful solar (MBtu)	216.53	235.99	145.86	1226.56
Auxiliary heat (MBtu)	413.20	256.22	38.02	2044.65

SUMMARY FOR AVERAGE HEATING SEASON (OCTOBER-APRIL):

Total internal heat:	795.0	MBtu	20%
Total useful solar heat:	1226.6	MBtu	30%
Total auxiliary heat:	2044.6	MBtu	50%

Total heat loss:	4066.2	MBtu	100%
HOME HEATING REQUIREMENT:	870511	Btu / DD	
HOME HEATING INDEX:	6.9	Btu / DD-sq. ft.	

UTILITY COSTS

 Costs below assume all internal heat generation is from electricity.

			Total annual heating cost	Average January bill (all fuels)	Average utility bill (October to April)
			-----	-----	-----
	54.53 cents/CCF natural gas 375 cents/gallon propane 354 cents/gallon fuel oil				
Electric resistance	1.00 = COP		\$0	\$306	\$306
Electric heat pump	2.00 = COP		\$0	\$306	\$306
Natural gas furnace	96 % = AFUE		\$11,614	\$3,495	\$1,965
Propane furnace	96 % = AFUE		\$87,856	\$24,431	\$12,857
Oil-fired furnace	96 % = AFUE		\$52,778	\$14,798	\$7,846

Appendix F

Heating Energy Analysis of Cheyenne and Arapaho Tribal College Design

ENERGY PERFORMANCE WORKSHEET FOR A BUILDING IN OKLAHOMA

Directions: Enter all information requested on screens 1 through 12 (screens are numbered at the bottom right). The numbers in the worksheet will recalculate automatically. Press key F10 to see a graph.

(C) Copyright 1985-1994 by Laurent Hodges, P. O. Box 1238, Ames, Iowa 50014-1238.

GENERAL INFORMATION ABOUT THE PROJECT

Enter below the name, address, and builder for the project.

PROJECT: The Cheyenne and Arapaho Tribal College
 ADDRESS: Weatherford, OK
 BUILDER: Riley Christopher-Gallagher, LEED AP

- 1-

3905 = HEATING DEGREE-DAYS AT PROJECT LOCATION

Enter approximate heating degree-days for the location of the project, using the numbers below as a guide.

6874 Ames	6671 Cedar Rapids	6482 Clinton
6200 Council Bluffs	6554 Des Moines	7375 Dubuque
7175 Fort Dodge	5587 Keokuk	7881 Mason City
6339 Ottumwa	6947 Sioux City	7537 Waterloo

GENERAL INFORMATION ABOUT THE HOUSE

125712 = TOTAL HEATED FLOOR AREA IN SQUARE FEET

Enter here the total heated floor area of the building in square feet. Count all levels, including the basement level if it is heated.

1,813,500 = INTERIOR VOLUME OF BUILDING IN CUBIC FEET

Enter here the interior volume of the building in cubic feet. This is the heated floor area times the average ceiling height. Count all heated spaces, including basement if it is heated.

- 2-

INFORMATION ABOUT WINDOWS

- 3 = TYPE OF WINDOWS. Enter the number corresponding to the main type of window used in the home:
- 1 for single-pane or ordinary double-pane windows
 - 2 for double-pane windows with night insulation
 - 3 for windows that are low-E or that have 3 or more panes.

On the next screen, use the manufacturer's U-value for the windows or estimate it from the following information:

- 1.13 for single-pane windows (1/4 inch thick)
- 0.55 for 1/8-inch double-pane windows, 1/4-inch air space
- 0.47 for 1/4-inch double-pane windows, 1/2-inch air space
- 0.44 for double-pane low-E windows, 1/4-inch air space
- 0.39 for 1/8-inch triple-pane windows, 1/4-inch air space
- 0.34 for 1/4-inch triple-pane windows, 1/2-inch air space

0.23 for Heat Mirror window (2 panes + H.M film)

- 3-

INFORMATION ABOUT WINDOWS

List the area, clear % (percentage of rough window area that consists of clear glass, usually 70-80 %), and U-value (using numbers on screen 4 as a guide) in the table below.

Area (sq. ft.)	Clear %	U	Description	
12000	100	0.30	South	Only what is on these 9 lines will be accepted.
4961	100	0.30	South	
4961	100	0.30	East	
0	100	0.30	East	
0	100	0.30	North	
4961	100	0.30	North	
4961	100	0.30	West	
4961	100	0.30	West	
6336	80	0.50	Skylights	

- 4-

INFORMATION ABOUT WALLS

Below, include information about the walls of the home. Include the opaque portions of the walls, but not the windows. The area should be the area above the conditioned space. Space is left to include a description of the different parts of the roof or ceiling if you have more than one part

Area (sq. ft.)	R	Description	
40996	30	Main Floor	Only what is on these 7 marked lines will be accepted.
0	29	Upper Floor	
0	15	Lower Floor	
0	5	Doors	

- 5-

INFORMATION ABOUT ROOF AND/ OR CEILING

Below, include information about the roof or ceiling of the home. Include only the opaque portions of the roof, not skylights. The area should be the area above the conditioned space. Space is left to include a description of the different parts of the roof or ceiling if you have more than one part

Area (sq. ft.)	R	Description	
46500	42	Ceiling - through insulation	Only what is on these
0	12	Ceiling - through insulation	

| 7 marked
| lines
| will be
| accepted.

- 6-

FLOORS OVER UNHEATED SPACES

Enter below the area and the R-value of any floors over unheated areas.

Area (sq. ft.)	R	Enter 0's if you have no floors over unheated spaces
0	40	

HEATED SLAB ON GRADE

Enter below the area and the R-value under any heated slab on grade.

Area (sq. ft.)	R	Enter 0's if you have no heated slab on grade
0	0	

- 7-

UNHEATED SLAB ON GRADE

Enter below the area and the R-value under any unheated slab on grade.

Area (sq. ft.)	R	Enter 0's if you have no unheated slab on grade
0	0	

CRAWL SPACE WALLS

Enter below the area and the R-value of the exterior walls of any crawl spaces below insulated floors.

Area (sq. ft.)	R	Enter 0's if you have no such crawl space walls
0	0	

- 8-

INFORMATION ABOUT BASEMENT WALLS

Area (sq. ft.)	R	M d- depth	Description
0	15	5	South Walls
0	15	3.25	East and North Walls
0	15	3.75	West Wall
0	0	0	

Enter above information about the basement walls of the building. In column A enter the area in square feet. In column B enter the R-value of the wall. In column C enter the depth (in feet) of the middle of the wall; for example, a wall extending from a depth of 0 feet to 7 feet would have a mid-depth of 3.5 feet. In column D, do not extend description past the last dash marks above and below.

This is limited to four lines of information.

- 9-

MISCELLANEOUS INPUT

0.5 = AIR CHANGES PER HOUR. Enter the estimated air infiltration rate in the home. For an energy-efficient home this is typically about 0.5 air changes per hour.

3750000 = AVERAGE DAILY TOTAL INTERNAL HEAT IN Btu. This number is not critical but has some effect on utility costs. A reasonable estimate is 25,000 times one more than the number of occupants of the home.

3 = AMOUNT OF THERMAL STORAGE. This is only important in passive solar homes. Enter the number corresponding to the amount of thermal storage in the building:

1. Low amount
2. Intermediate amount
3. High amount

- 10-

INFORMATION ABOUT POSSIBLE HEATING SYSTEMS

The input numbers on this page are used only to determine the estimated utility costs for an average heating season. If you are using an electric heat pump or a gas furnace in the home, be sure to put in the correct value below.

5.20 = SCOP FOR ELECTRIC HEAT PUMP
Enter the seasonal COP (coefficient of performance) of the electric heat pump to be installed.

96 % = AFUE FOR GAS, PROPANE OR OIL-FIRED FURNACE
Enter the AFUE (Annual Fuel Utilization Efficiency) of the natural gas or propane or oil-fired furnace to be installed.

- 11-

ENERGY PRICES

Enter below the prices of energy for your locality. It is the price of the energy used as a heating fuel that is relevant.

PRICE OF ELECTRICITY:

9.7 cents per kWh for first 2000 kWh
 5.7 cents per kWh for next 2000 kWh
 0.0 cents per kWh above that

54.53 cents per therm (100,000 Btu) = PRICE OF NATURAL GAS

375 cents per gallon = PRICE OF PROPANE

354 cents per gallon = PRICE OF FUEL OIL

- 12-

SUMMARY OF COMPLIANCE WITH IOWA ENERGY CODE

Home Heating Index: 2.63 Btu/degree-day per square foot

Comparison of project with 1992 Model Energy Code requirements:

		CODE	PROJECT
Walls:	maximum U =	0.150	0.126
Roof / Ceiling:	maximum U =	0.036	0.081
Floors over unheated spaces:	maximum U =	0.050	0.025
Heated slab on grade:	minimum R =	5.5	0.000
Unheated slab on grade:	minimum R =	3.6	0.000
Basement wall:	maximum U =	0.101	0.000
Crawl space wall:	maximum U =	0.060	0.000

- 13-

December 1994 version of worksheet prepared by:

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This spreadsheet is intended to allow you to check if an Iowa home meets the component standards of the 1992 Model Code. It will also estimate the heat loss and utility costs for a typical Iowa single-family home or duplex with a basement. It works less well for bigger buildings or slab-on-grade homes, for which the heat loss depends on details of the foundation wall insulation that require a more sophisticated model, and cannot be accurately modeled in terms of Btu per degree-day.

 BUILDING HEAT LOSS ESTIMATE

EFFECTIVE
 SQ. FT. R VALUE Btu/ DD



Walls,	41075	30.1	32797	Walls
ceilings,	46500	42.0	26571	Roof / ceiling
and	0	40.0	0	Floors over unheated spaces
floors	0	0.0	0	Heated slab on grade
	0	0.0	0	Unheated slab on grade
	0	0.0	0	Basement walls
	0	0.0	0	Crawl space walls
Windows	12000	3.3	86400	South windows
	9922	3.3	71438	East / West windows
	0	0.0	0	North windows
	6336	2.0	76032	Skylights
AIR INFILTRATION HEAT LOSS:			391716	Btu / degree-day
BUILDING HEAT LOSS COEFFICIENT:			684954	Btu / degree-day
ESTIMATED HEATING LOAD:			1940704	Btu / hour at winter dry-bulb T

Abbreviations: Btu = British thermal units
 DD = Fahrenheit heating degree-day
 MBtu = Million Btu

THERMAL PERFORMANCE

ASSUMED AIR CHANGES PER HOUR:		0.50	air changes per hour	
BUILDING HEAT LOSS COEFFICIENT:		684954	Btu / DD	
MAXIMUM HEATING SYSTEM LOAD:		1,940,704	Btu / hour	
	OCT	NOV	DEC	JAN
Heating degree-days	197	462	678	770
Gross heat loss (MBtu)	135.02	316.35	464.60	527.25
Internal heat (MBtu)	116.25	112.50	116.25	116.25
Net heat loss (MBtu)	18.77	203.85	348.35	411.00
Solar Gain (MBtu)	405.54	314.34	329.89	419.26
Solar Load Ratio (SLR)	21.604	1.542	0.947	1.020
Solar Heating Fraction	0.999	0.836	0.625	0.662
Useful solar (MBtu)	18.76	170.47	217.88	271.95
Auxiliary heat (MBtu)	0.01	33.38	130.47	139.04
	FEB	MAR	APR	TOTAL
Heating degree-days	638	528	257	3531
Gross heat loss (MBtu)	436.97	361.87	176.27	2418.32
Internal heat (MBtu)	105.00	116.25	112.50	795.00
Net heat loss (MBtu)	331.97	245.62	63.77	1623.32
Solar Gain (MBtu)	408.06	431.09	330.79	2638.97
Solar Load Ratio (SLR)	1.229	1.755	5.187	
Solar Heating Fraction	0.747	0.878	0.998	
Useful solar (MBtu)	248.01	215.70	63.66	1206.43
Auxiliary heat (MBtu)	83.96	29.92	0.10	416.89

SUMMARY FOR AVERAGE HEATING SEASON (OCTOBER-APRIL):

Total internal heat:	795.0	MBtu	33%
Total useful solar heat:	1206.4	MBtu	50%
Total auxiliary heat:	416.9	MBtu	17%

Total heat loss:	2418.3	MBtu	100%
HOME HEATING REQUIREMENT:	331245	Btu / DD	
HOME HEATING INDEX:	2.6	Btu / DD-sq. ft.	

UTILITY COSTS

 Costs below assume all internal heat generation is from electricity.

		Total annual heating cost	Average January bill (all fuels)	Average utility bill (October to April)
		-----	-----	-----
	54.53 cents/CCF natural gas 375 cents/gallon propane 354 cents/gallon fuel oil			
Electric resistance	1.00 = COP	\$0	\$306	\$306
Electric heat pump	5.20 = COP	\$0	\$306	\$306
Natural gas furnace	96 % = AFUE	\$2,368	\$1,096	\$644
Propane furnace	96 % = AFUE	\$17,913	\$6,281	\$2,865
Oil-fired furnace	96 % = AFUE	\$10,761	\$3,895	\$1,843

References Cited

- Amstock, Joseph S. (1997). Handbook of glass in construction. New York, NY: McGraw-Hill.
- Asif, M. (2009). Sustainability of timber, wood and bamboo in construction. In Jamal M. Khatib (Ed.), Sustainability of construction materials. Cambridge, UK: Woodhead.
- Athienitis, A.K. & Santamouris, M. (2002). Thermal analysis and design of passive solar buildings. London: James & James.
- Atkins, C. (2009). Sustainability of glass in construction. In Jamal M. Khatib (Ed.), Sustainability of construction materials. Cambridge, UK: Woodhead.
- AtKisson, Alan. (2006). Sustainability is dead – long live sustainability. In Marco Keiner (Ed.), The future of sustainability. Dordrecht, Netherlands: Springer.
- Balkema, A.A. (1992). Fly ash as addition to concrete. Rotterdam: Brookfield.
- Berge, Bjorn (2000). Ecology of building materials. Woburn, MA: Architectural Press.
- Block, David. (2011). Solar Home Design. Iowa State University: Course ARCH 351 Lecture Notes.
- Bose, James E. (Project Director). (1997). Geothermal heat pumps: introductory guide. Stillwater, OK: Oklahoma State University.
- Bouzoubaa, N., Bilodeau, A., Sivasundaram, V. & Chakraborty, A. K. (2007). Mechanical properties and durability characteristics of high-volume fly ash concrete made with ordinary Portland cement and blended Portland fly ash cement. In V. M. Malhotra (Ed.), Fly ash, silica fume, slag, and natural pozzolans in concrete. Farmington Hills, MI: American Concrete Institute.
- Boyer, Lester L. & Grondzik, Walter T. (1987). Earth shelter technology. College Station, TX: Texas A&M University Press.
- Bureau of Indian Affairs 2005 Labor Force Report. Retrieved from the World Wide Web on October 18, 2010 at <http://www.bia.gov/idc/groups/public/documents/text/idc-001719.pdf>
- Calkins, Meg (2009). Materials for sustainable sites: A complete guide to the evaluation, selection, and use of sustainable construction materials. Hoboken, NJ: Wiley & Sons.

- Chen, Olivia. (2008). Living machines: clean, green waste-water recycling. Inhabitat. Retrieved March 14, 2011 from the World Wide Web: <http://inhabitat.com/living-machines-turning-wastewater-clean-with-plants/>
- Cheyenne and Arapaho Tribal Constitution. Retrieved from the World Wide Web on October 1, 2010 at <http://www.c-a-tribes.org/cheyenne-arapaho-tribes-constitution>
- Cheyenne and Arapaho Tribal Tribune (May 15, 2009) Economic developments – cattle purchase. Retrieved from the World Wide Web on November 27, 2010 at <http://www.c-a-tribes.org/tribal-newspaper-archive>
- Cheyenne and Arapaho Tribal Tribune (June 1, 2009). Retrieved from the World Wide Web On November 5, 2010 at <http://www.c-a-tribes.org/tribal-newspaper-archive>
- Cheyenne and Arapaho Tribes Official Website. Retrieved from the World Wide Web on October 1, 2010 at <http://www.c-a-tribes.org>
- Clement, Douglas. (2009). Growth by degrees. In Linda Sue Warner & Gerald E. Gipp (Eds.), Tradition and culture in the millennium: tribal colleges and universities. Charlotte, NC: Information Age Publishing.
- Concrete Joint Sustainability Initiative Website. Retrieved March 10, 2011 from the World Wide Web: <http://www.sustainableconcrete.org/>
- Cordeiro, Eduardo E. (1992). The economics of bingo: factors influencing the success of bingo operations on American Indian reservations. In Stephen Cornell & Joseph P. Kalt (Eds.), What can tribes do? Strategies and institutions in American Indian economic development. Los Angeles, CA: University of California, Los Angeles.
- Cornell, Stephen; Jorgensen, Miriam; Record, Ian Wilson & Timeche, Joan (2007). Citizen entrepreneurship: an underutilized development resource. In Miriam Jorgensen (Ed.), Rebuilding Native nations. Tucson, AZ: University of Arizona Press.
- Cornell, Stephen & Kalt, Joseph P. (2008). The state of the native nations: conditions under U.S. policies of Self-Determination. The Harvard project on American Indian economic development. New York: Oxford.
- Crazybull, Cheryl. (2009). Tribal colleges and universities: from where we are to where we might go. In Linda Sue Warner & Gerald E. Gipp (Eds.), Tradition and culture in the millennium: tribal colleges and universities. Charlotte, NC: Information Age Publishing.
- Crosbie, Michael J. (Ed.) (1998). The passive solar design and construction handbook. New York: John Wiley & Sons.

- Cusack, Victor (1999). Bamboo world: the growing and use of clumping bamboos. East Roseville, NSW: Kangaroo Press.
- Daly, Herman E. & Farley, Joshua. (2011). Ecological economics. Washington, D.C.: Island Press
- Demkin, Joseph A. (1998). Environmental Resource Guide. New York: Wiley.
- Edelhart, Mike. (1982). The handbook of earth shelter design. New York: Dolphin.
- Egg, Jay & Howard, Brian Clark. (2011). Geothermal HVAC: green heating and cooling. New York: McGraw-Hill.
- Elkadi, Hisham. (2006). Cultures of glass architecture. Burlington, VT: Ashgate.
- Environmental Protection Agency (1991). Markets for scrap tires. Retrieved March 10, 2011 from the World Wide Web:
<http://www.epa.gov/wastes/conserves/materials/tires/tires.pdf>
- Ernst, Randi L. (1997). Inert Gases. In Joseph S. Amstock (Ed.), Handbook of glass in construction. New York, NY: McGraw-Hill.
- Findlay, Laura. (2005). Building change. New York: Routledge.
- Fowler, L. (2006). The Arapaho Indians of North America. New York: Chelsea House.
- Francis, Carolee Dodge. (2009). The art of looping linear: perspectives from tribal college students and faculty. Saarbrucken, Germany: VDM Verlag.
- Gipe, Paul. (2004). Wind power: renewable energy for home, farm and business. White River Junction, VT: Chelsea Green.
- Glavind, M. (2009). Sustainability of cement, concrete and cement replacement materials in construction. In Jamal M. Khatib (Ed.), Sustainability of construction materials. Cambridge, UK: Woodhead.
- Haselbach, Liv. (2010). The engineering guide to LEED – New Construction. New York: McGraw-Hill.
- Hastings, S.R. (1994). Passive solar commercial and institutional buildings. West Sussex, UK: Wiley & Sons.
- Hoig, S. (2006). The Cheyenne Indians of North America. New York: Chelsea House.
- Hurd, Simon. (2006). The living machine: ecological wastewater treatment. Retrieved March 29, 2011 from the World Wide Web:
<http://www.spur.org/documents/20060413LivingMachine.pdf>
- Judziewicz, Emmet J., Clark, Lynn G., Londono, Ximena & Stern, Margaret J. (1999). American bamboos. Washington, D.C.: Smithsonian Institution Press.

- Keiner, Marco. (2006). Advancing sustainable development and its implementation through spatial planning. In Marco Keiner (Ed.), The future of sustainability. Dordrecht, Netherlands: Springer.
- Kibert, C. J. (1994). Concrete/masonry recycling progress in the USA. In Erik K. Lauritzen (Ed.), Demolition and reuse of concrete and masonry: Proceedings of the third international RILEM symposium (pp.83-91). Suffolk, UK: Edmundsbury Press.
- Kidwell, Clara Sue & Velie, Alan. (2005). Native American studies. Edinburgh, UK: Edinburgh University Press.
- Klodt, Gerald J. (1985). Earth sheltered housing. Reston, VA: Reston Publishing.
- Kretzmann, John P. & McKnight, John L. (1993). Building communities from the inside out. Skokie, IL: ACTA Publications.
- Krinsky, Carol Herselle. (1996). Contemporary Native American architecture. New York: Oxford.
- Lambert, P. (2009). Sustainability of metals and alloys in construction. In Jamal M. Khatib (Ed.), Sustainability of construction materials. Cambridge, UK: Woodhead.
- Langer, W. (2009). Sustainability of aggregates in construction. In Jamal M. Khatib (Ed.), Sustainability of construction materials. Cambridge, UK: Woodhead.
- Lesiak, Christine. (2007). In the white man's image: the tragic attempt to "civilize" Native Americans in the 1870s. [DVD Video]. Boston, MA: WGBH Video.
- Light, Steven Andrew & Rand, Kathryn R.L. (2005). Indian gaming and tribal sovereignty: the casino compromise. Lawrence, KS: University Press of Kansas.
- Londono, Ximena (2003). A sustainable timber resource of incalculable value. In Marcelo Villegas (Ed.), New bamboo: architecture and design. Bogota: Villegas Editores.
- Malolepszy, J. & Tkaczewska, E. (2007). Fly ash from co-burning bituminuous coal and biomass – effect on properties of cement. In V. M .Malhotra (Ed.), Fly ash, silica fume, slag, and natural pozzolans in concrete. Farmington Hills, MI: American Concrete Institute.
- Mann, Henrietta. (1997). Cheyenne-Arapaho education 1871-1982. Niwot, Colorado: University Press of Colorado.
- Manwell, J.F., McGowan, J.G. & Rogers, A.L. (2002). Wind energy explained: theory, design and application. New York: Wiley.
- Mazria, Edward. (2011). Architecture 2030 challenge. Retrieved on January 25, 2011 from the World Wide Web at: <http://architecture2030.org/>

- Mazria, Edward. (1979). The passive solar energy book. Emmaus, PA: Rodale.
- McClure, F.A. (1972). Bamboo and reeds in building construction. New York: United Nations.
- McLeod, Christopher (Director). (2002). In the light of reverence. [DVD Video]. Oley, PA: Bullfrog Films.
- Mehta, P. Kumar. (2001, October). Reducing the environmental impact of concrete: concrete can be durable and environmentally friendly. Concrete International, 61-66.
- Mehta, P. Kumar. (2003). High-performance, high-volume fly ash concrete for sustainable development. University of California, Berkeley. Retrieved March 21, 2011 from the World Wide Web at:
<http://www.intrans.iastate.edu/pubs/sustainable/mehtasustainable.pdf>
- Milner, H. R. (2009). Sustainability of engineered wood products in construction. In Jamal M. Khatib (Ed.), Sustainability of construction materials. Cambridge, UK: Woodhead.
- Moore, J. (1993). The political economy of North American Indians. Norman, Oklahoma: University of Oklahoma Press.
- Musgrove, Peter. (2010). Wind power. Cambridge, UK: Cambridge University Press.
- Nabokov, Peter & Easton, Robert. (1989). Native American architecture. New York: Oxford.
- Nijse, Rob. (2003). Glass in structures. Basel, Germany: Birkhauser.
- Ochsner, Karl. (2008). Geothermal heat pumps: a guide for planning & installing. London: Earthscan.
- Oklahoma Tribal Governmental Gaming Report dated: October of 2001 through March 1, 2002. Retrieved from the World Wide Web on November 11, 2010 at
<http://tribalgovernmentgaming.com/>
- Paxson, Lynn. (2010). Native American architecture and place-making. Iowa State University: Course ARCH 426 Lecture Notes.
- Pember, Mary Annette. (2008). A tribal college with an 'edge.' Retrieved January 18, 2011 from the World Wide Web: <http://diverseeducation.com/article/11266/>
- Penalosa, E. (2007). Politics, power, cities. In Richard Burdett (Ed.), The endless city. New York: Phaidon Press.
- Portland Cement Association (1997). United States Portland cement plants: ranked by size largest to smallest. Retrieved March 9, 2011 from the World Wide Web:
<http://www.epa.gov/ttn/atw/pcem/plantlis.pdf>

- Rader, Brian F, Oklahoma Indian Welfare Act (1936). In Encyclopedia of Oklahoma history and culture. Retrieved from the World Wide Web November 15, 2010 at <http://digital.library.okstate.edu/encyclopedia/entries/O/OK059.html>
- Reiner, Mark, Pitterle, Mark & Whitaker, Michael. (2007). Embodied energy considerations in existing LEED credits. Boulder, CO. Retrieved from the World Wide Web on October 18, 2010 at: <http://www.symbiotic-engineering.com>
- Roosa, Stephen A. (2008). Sustainable development handbook. Lilburn, GA: The Fairmont Press.
- Schendler, Auden. (2009). Getting green done. New York: PublicAffairs.
- Schmitt, Gotz (1999). Industrial uses of guadua. In Marcelo Villegas (Ed.), New bamboo: architecture and design. East Roseville, NSW: Kangaroo Press.
- Schuler, Matthias & Reuss, Stefanie (2007). Glass and energy – building performance. In Steffi Lenzen (Ed.), Glass construction manual. Berlin, Germany: Birkhauser.
- Sear, Lindon K.A. (2001). The properties and use of coal fly ash. London: Thomas Telford Publishing.
- Selman, Paul. (1996). Local sustainability. New York: St. Martin's Press.
- Smith, Dean Howard. (2000). Modern tribal development. Walnut Creek, CA: AltaMira Press.
- Snodgrass, Edmund C. & Snodgrass, Lucie L. (2006). Green roof plants: a resource and planting guide. Portland, OR: Timber Press.
- Solomon and Shirley. Tribal/county cooperation: making it work at the local level. Course reading at South Dakota State University: Course CDEV 507. Retrieved from the World Wide Web on November 1, 2010 at: <http://www.culturalsurvival.org/ourpublications/csq/article/tribalcounty-cooperation-making-it-work-local-level>
- Spence, William P. & Kultermann, Eva. (2011). Construction materials, methods, and techniques: Building for a sustainable future. New York: Delmar Cengage Learning.
- Speth, James Gustav. (2005). Creating a sustainable future: are we running out of time? In Robert Olson & David Rejeski (Eds.), Environmentalism & the technologies of tomorrow. Washington, D.C.: Island Press.

- Stein, Wayne J. (2009). Tribal colleges and universities: supporting the revitalization in Indian country. In Linda Sue Warner & Gerald E. Gipp (Eds.), Tradition and culture in the millennium: tribal colleges and universities. Charlotte, NC: Information Age Publishing.
- Stephens, Rosemary. (November 1, 2010). Wind energy, the future. In Cheyenne and Arapaho Tribal Tribune. Retrieved on February 15, 2011 from the World Wide Web at:
<http://www.catribes.org/Websites/michaelwood/Images/Newspapers/NewsPaper%202010/Nov.%201,%202010.pdf>
- Wainwright, P.J., & Trevorrow, A., & Wang, Y., & Yu, Y. (1994). Modifying the performance of concrete made with coarse and fine recycled concrete aggregates. In Erik K. Lauritzen (Ed.), Demolition and reuse of concrete and masonry: Proceedings of the third international RILEM symposium (pp.319-330). Suffolk, UK: Edmundsbury Press.
- Warner, Linda Sue & Tijerina, Kathryn Harris. (2009). Indigenous governance. In Linda Sue Warner & Gerald E. Gipp (Eds.), Tradition and culture in the millennium: tribal colleges and universities. Charlotte, NC: Information Age Publishing.
- Welch, Debora. (2006). Contemporary Native American issues: economic issues and development. Philadelphia, PA: Chelsea House.
- Weller, Bernhard, Harth, Kristina, Tasche, Silke, & Unnewehr, Stefan (2009). Glass in building. Basel, Germany: Birkhauser.
- Werbach, Adam. (2009). When sustainability means more than green. In McKinsey Quarterly. Retrieved on February 18, 2011 from the World Wide Web at:
http://www.mckinseyquarterly.com/When_sustainability_means_more_than_green_2404
- Wigginton, Michael. (1996). Glass in architecture. London: Phaidon Press.
- Wildcat, Daniel R. (2009). Red alert: saving the planet with indigenous knowledge. Golden, CO: Fulcrum.
- Williams, Robin & Pewewardy, Cornel. (2009). Student retention initiatives at tribal colleges and universities. In Linda Sue Warner & Gerald E. Gipp (Eds.), Tradition and culture in the millennium: tribal colleges and universities. Charlotte, NC: Information Age Publishing.
- Wurm, Jan. (2007). Glass structures. Basel, Germany: Birkhauser.

- Wyckmans, Annemie, Ascheloug, Oyvind, Hestnes, & Hestnes, Anne Grete (2007). Intelligent building envelopes application in the field of daylighting. In Michel Crisinel, Mick Eekhout, Matthias Haldimann, & Ronal Visser (Eds.), Glass & interactive building envelopes (pp.85-94). Amsterdam, Netherlands: IOS Press.
- UNH - University of New Hampshire. (2011). Sustainability academy. Retrieved on March 8, 2011 from the World Wide Web at:
http://www.sustainableunh.unh.edu/culture_sust/whyculture.html
- US News. Nursing home ratings. Retrieved from the World Wide Web on December 1, 2010 at <http://health.usnews.com/senior-housing/nursing-homes/ok/geary-community-nursing-home-375533>
- Yudelson, Jerry. (2008). The green building revolution. Washington, D.C.: Island Press.