Chapter 1

Introduction

In 1998, a ban on the cultivation of industrial hemp in Canada was ended with the passing of the *Industrial Hemp Regulations.* Shortly thereafter, I received a call from a neighboring farmer, Grant Moorcroft. He was aware that I had been building with straw bales for a few years, and he wanted me to come and check out the bales of hemp straw he had made from his first hemp crop and see if they would be useful as building bales.

As it turned out, the hemp straw bales (made from the stalks of hemp grown for seed production) made excellent building bales, and I went on to use them on many projects.

At that same time, the Internet was starting to play an important role in my sustainable building research, and high on the list of interesting information I was finding online was a material called "hempcrete." All of the early information I could find about hempcrete was from France, and from what I could discern across the language barrier, this material was a mixture of chopped hemp stalks and lime. The recipes were all proprietary, so there was little else to discern other than the basic materials.

Armed with this minimal amount of information, Grant and I began chopping up his hemp stalks and playing with hempcrete recipes. Right from the very first experiments, I was excited and enthusiastic about this material. Our results provided a material that was relatively low-density and would obviously have good insulation properties. At the same time, the material had a body and integrity to it that allowed it to be formed into bricks and blocks with some structural properties. The material could be sculpted and formed. It made an excellent substrate for plaster. I was intrigued.

Early on, I started burying some of the sample blocks to see how they would react to constant exposure to moisture. After one year, I dug out the first buried samples and was impressed to find that there had been no noticeable deterioration. I put them back in the ground, and checked them again at years two and three with the same result, suggesting that this bio-fiber insulation provides resistance to moisture in a way that far exceeds other bio-fiber insulations — very important in the northern climate where I build.

I first used hempcrete in a code-approved building in 2005, casting hempcrete insulated window header sections in a straw bale building and creating one interior infill wall. By 2008, I was using hempcrete to cast fully insulated frame walls, to create sub-slab insulation and to insulate around windows. Many subsequent projects included hempcrete in one form or another.

There was a hiatus in my use of hempcrete for a few years, because Grant decided to stop growing hemp. After a brief period of enthusiastic adoption by farmers in Ontario, the lack of markets for hemp materials in our region led many farmers to cease production. Unfortunately, this situation exists today. It has meant that an important and valuable regional building material cannot be acquired locally. I look forward to the day when this situation is reversed and local farmers once again plant, cultivate, process and sell hemp products locally.

Hempcrete has remained an important part of my building practice, despite having to import the hemp material from another region of Canada. As the European experience has shown, hempcrete insulation has the potential to take an important role in greening our built environment. Academic and government interest in hemp building products has created a healthy market for European hempcrete in just a decade. Since the early work documented in the first book about hempcrete, *Building with Hemp* by Steve Allin in 2005, the number of hempcrete buildings in the UK, France, Germany and other European countries has grown exponentially. Meanwhile, in North America only a small handful of dedicated builders work on developing methods and materials here.

The main reason for the large gap in hempcrete development between Europe and North America is the continued ban on industrial hemp farming in the U.S. The failure of legalized hemp farming in Canada to result in the creation of significant processing facilities shows that without legalization and the development of markets in the U.S., any use of hemp materials on this continent will remain a fringe activity. At the time of writing, there are some positive indications that American federal and state government are moving to relax restrictions on industrial hemp farming. It is now imaginable that a critical mass of farmers and production facilities in the U.S. is possible within a matter of years.

This book is a hopeful precursor to the wide availability of hempcrete materials in North America. The materials and techniques presented here are even now feasible, affordable and practical. The creation of new material sources will help hempcrete in North America follow the positive trajectory of the material in Europe. I encourage forward-looking green builders to jump on board now!

Chapter 2

Rationale

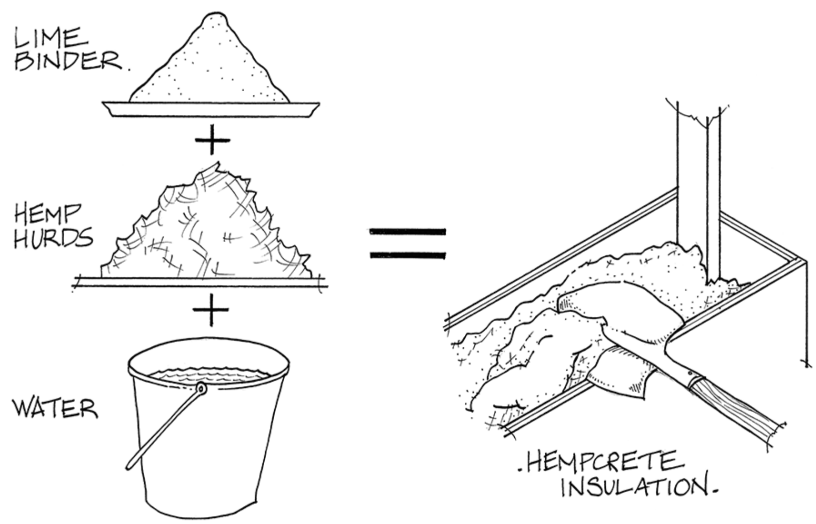
Hempcrete (or *hemp-lime,* as it's commonly called in Europe) is a promising building insulation material. It is also the subject of more hype and hyperbole than any other sustainable building material. Proponents of hemp-based products tend toward unsupported or exaggerated claims of performance and planetary benefit with Websites that make the material seem miraculous.

In truth, hempcrete is simply a very good building insulation material, and there are plenty of compelling reasons to consider using it. It makes an excellent addition to the sustainable builder's "tool kit" of more people- and planet-friendly building solutions. Hempcrete alone will not save the planet, but it will provide an excellent insulation material to a project with the right criteria and context. This book is intended to highlight both the advantages *and* disadvantages of hempcrete and provide potential users with reliable and tested information.

What Is Hempcrete?

Hempcrete is a unique building material, being a *composite* of a bio-fiber (hemp *hurd* or *shiv*) and a mineral binder (lime). These ingredients are blended together with water, and the moistened binder coats all the particles of hemp shiv. A chemical reaction occurs between the lime binder and the water, resulting in the binder setting and gluing the hurd particles together. Generically, it could be called "bonded cellulose insulation."

When the binder is set and cured and any additional water has dried out of the mixture, the resulting material is hempcrete. Unlike many construction composites (such as concrete, mortar and plaster), the binder portion in hempcrete is not intended to fill all the voids between the hemp particles, but only to coat the particles and cause them to adhere to one



The void space in a hempcrete mix creates pockets of trapped air and is part of the reason the material has desirable thermal properties.

Hemp with lots of fiber.

Hemp with a bit of fiber.

Hemp with some fiber.

The fiber content of the hemp hurd will have a large impact on the qualities of the final mixture. A high percentage of fiber increases density and strength at the expense of thermal performance. Most hempcrete mixtures use little or no fiber.

another where they touch. A hempcrete mix typically has a high percentage of void space in the final mixture.

Hempcrete has a range of desirable thermal, structural and moisture-handling properties that make for an excellent building insulation material. Depending on the mix variables described in this book, hempcrete can be used as roof, wall and/or slab insulation.

Accounting for the variables

Any discussion of hempcrete is complicated by the fact that all three elements in the bio-composite can have a range of types and characteristics, and can be added to the mix in varying ratios.

Hemp hurd

The hemp hurd is the woody core of the hemp plant. It is typically sourced from hemp fiber producers after the valuable hemp fiber has been stripped from the outside of the hemp stalk, leaving the hurd as a by-product.

Variables in the hurd portion of the hempcrete composite include size and grading of the hurd and volume and length of hemp fiber.

Desirable properties for hurd are given in the Material Specifications chapter of this book.

Lime binder

Lime has been an important binder in construction for thousands of years, largely in mortar and plaster recipes. There are different types and grades of lime, and there are various additives that may be included in the binder ratios. These variables will affect the setting time, strength and durability of the hempcrete mixture. There are several brands of manufactured lime binders made specifically for use in hempcrete, and there are recipes for creating lime binder from separate ingredients. The specific qualities that are ideal for a lime binder for hempcrete are discussed in the Material Specifications chapter.

Water

The volume of water added to a hempcrete mixture will have a dramatic effect on the results, even if the hurd and lime variables are controlled. Hemp hurd is extremely porous, capable of absorbing a volume of water that is much larger than what is required for a good hempcrete mixture. Too much water in a mixture can result in higher density, issues with setting for the lime binder, and excessively long drying times for the hempcrete.

Placement and tamping

The final — and also critical — variable is the placement of hempcrete into the building. In wall and floor applications, the material requires some manual tamping in order to ensure that the mix is well bonded and has integrity. However, the amount of tamping can have a major impact on the density of the final material, even if all the mix ratios are identical. Variations in density can have a large impact on thermal performance, so this is an important variable to try to control. This will be covered in the Construction Procedure chapter of this book.

Limitations in quantifying hempcrete

A great deal of this book is intended to help builders find the ideal ingredients and mixtures in order to be able to use hempcrete successfully. But the variability in the formulations and ingredients make it difficult to make blanket generalizations about the performance parameters of hempcrete, especially compared to manufactured insulation products that come from a factory with little or no variation.

Throughout this book, a concerted effort has been made to use relevant testing data, based on knowledge of the variables, and pointing out where the testing data is incomplete or inconclusive.

Why Hempcrete?

The building industry does not see very many "new" materials. The materials used to insulate residential and commercial buildings have remained the same for decades, and most have serious environmental and/or health impacts. As we collectively begin to add more insulation to buildings to lower their energy requirements, the volume of insulating material we use is going to rise dramatically. It makes ecological and financial sense to fill this volume with materials that are annually renewable, low-impact and, ideally, sourced from waste streams or from by-products from other processes. Hempcrete meets all of these important criteria, and compares favorably with conventional insulation materials in many ways.

Affordable insulation

The ingredients for making hempcrete are not common building materials, and as such they do not benefit from the volume price breaks of other insulation options. Still, even prior to wide market availability and the cost reductions this will bring, the cost of hempcrete is comparable

Table 2.1

Material	Approximate cost of 1 square foot of wall surface area @ ~R-28*	Thickness of insulation
Hempcrete	\$3.50 @ \$3.00/ft^3 \$11.66 @ \$10.00/ft^3	14 inches
Mineral wool batt	\$1.40	7 inches
Fiberglass batt	\$1.20	8.5 inches
Denim batt	\$1.80	8 inches
Dense packed cellulose	\$1.45	9 inches
Extruded polystyrene foam	\$4.40	5.75 inches
Expanded polystyrene foam	\$4.20	7.5 inches
	* cost averages from retail building supply Websites, 2015	

with other insulation options, while bringing advantages over those options in other ways.

The variability in hempcrete pricing is reflected in the chart below, showing that proper attention must be paid to sourcing affordable materials. Hemp sourced from Canadian producers is considerably less expensive than that imported from Europe.

Excellent moisture handling and resistance

Hempcrete is unique among the plant-fiber insulation materials (cellulose, wood fiber, straw bale, straw/clay, cotton) in its ability to maintain integrity in humid conditions. Like all of the plant-fiber insulation options, hemp hurds are able to store a great deal of moisture because of their porous structure; the moisture is *ad*sorbed onto the large internal surface area of the plant fibers and *ab*sorbed into the cellular structure. This storage capacity is very helpful in allowing the material to take on moisture when it exists and to release it when conditions allow. A study performed in France[1] found that up to 596 kilograms (1314 pounds) of water vapor could be stored in 1 cubic meter (35.3 ft^3) of hempcrete, providing storage capacity for a sustained elevated relative humidity of 93% without overwhelming the capacity of the material to adsorb moisture.

The advantage of hempcrete over other plant-fiber materials and conventional insulation types is found in the properties of the lime binder. Lime has a high pH and is inherently antimicrobial and antifungal, and the lime coating around each piece of hemp hurd in the mix creates a surface that resists the development of mold even when the humidity and temperature conditions would cause mold to occur on other insulation materials. This resilience in the presence of humidity or even liquid moisture makes hempcrete unique among insulation materials and a desirable choice in both cold and hot climates and anywhere where humidity levels are high.

Good structural qualities

Hempcrete has a density that allows it to play a minor structural role in the building — unlike batt, loose fill and spray insulation materials in the cost chart above. Hempcrete insulation does *not* have the structural capacity to fully support roof loads, but cast around conventional wall framing or double-stud framing, it can help restrain the studs from bending or buckling under loads, thereby increasing the load that can be carried by each framing member. Testing at Queen's University in Canada showed that a 2×6 wood stud with 313 kg/m^3 (19.5 lb/ft^3) hempcrete infill could support three to four times the compressive loading of a standard stud wall due to the support the hempcrete provides to the wood stud in weak axis bending.[2]

The rigidity of hempcrete insulation and the textured surface it presents on the face of the wall makes an excellent substrate for plaster finishes without any need for mesh or other bonding agents.

An agricultural by-product

Hemp is an agricultural crop that has particularly high yields. A study by the US Department of Agriculture found worldwide yields ranged between 2.5 to 8.7 tons of dry straw per acre.[3] This compares favorably to yields for wheat straw of 1.25 to 2.5 tons per acre.[4] In terms of the amount of biomass available for use from a single crop, no other plant provides as much volume as hemp.

The hemp plant is typically grown for either the strong fiber it produces or for seed (rarely for both at the same time). In either type of hemp production, the hurd is not the primary use and is considered a by-product. It has some market value as animal bedding and can be compressed into fuel pellets, but large-scale hemp production can generate tons of hurd for the insulation market as producers supply fiber or seed to their primary markets.

Good carbon sequestration

According to a 2003 study, 716.6 pounds (325 kg) of CO_2 are stored in one tonne of dried hemp[5]. Tradical, a hempcrete manufacturer in the UK, cites a study showing that their hempcrete product sequesters 110 kg of CO_2 for every cubic meter of material (6.88 pounds per cubic foot)[6] when the carbon emissions from producing the lime binder are taken into account.

In Canada, about 200,000 new homes are built each year, with an average footprint of 2,000 square feet (185 m^2). If they were all insulated to code minimum requirements with hempcrete, a total of 990,718 tons of carbon could be sequestered annually. If the same homes had walls with fiberglass insulation, 207,345 tons of carbon would be *emitted* [7] to create that insulation, so the total net carbon savings for the planet is significant.

Nontoxic building material

Hempcrete is quite a benign material. The farming process uses far fewer pesticides and herbicides than other grain or fiber crops,[8] creating much less environmental damage due to the use of toxins on the fields. The crop does, however, require liberal use of fertilizer, which can have negative ecosystem impacts. Harvesting and processing take place without the input of heat or chemicals.

The dry, powdered lime binder can generate a lot of dust during mixing, and is highly caustic. Adequate breathing protection must be worn by anybody handling the dry ingredients and working around the mixing station. When wet, the lime binder is mildly caustic to skin, so rubber gloves and fully covered skin are required.

Once placed in the wall and fully cured and dry, hempcrete does not off gas or release any toxins into the indoor environment. The lime is antimicrobial and antifungal, and the material is generally thought to have no ill effects on the indoor environment. The excellent moisture-handling abilities of the material can reduce

Table 2.2

Material	Embodied carbon by weight*	Embodied carbon for 4x8 foot wall @ R-28**	Carbon footprint after sequestration
Hempcrete	-2.73 $kgCO_2e/kg$ for 300 kg/m^3 mix	-121.4 $kgCO_2e$	-121.4 kg per 4x8 wall area
Mineral wool batt	1.28 $kgCO_2e/kg$	21.75 $kgCO_2e$	21.75 kg per 4x8 wall area
Fiberglass batt	1.35 $kgCO_2e/kg$	17.6 $kgCO_2e$	17.6 kg per 4x8 wall area
Denim batt	1.28 $kgCO_2e/kg$	22.45 $kgCO_2e$	-1.5 kg per 4x8 wall area
Dense packed cellulose	0.63 $kgCO_2e/kg$	35.3 $kgCO_2e$	-41.3 kg per 4x8 wall area
Extruded polystyrene foam	3.42 $kgCO_2e/kg$	38.5 $kgCO_2e$	38.5 kg per 4x8 wall area
Expanded polystyrene foam	3.29 $kgCO_2e/kg$	37.25 $kgCO_2e$	37.25 kg per 4x8 wall area
	* figures from Inventory of Carbon and Energy (ICE) 2.0	**material densities from *Making Better Buildings*	

the chances of a poor indoor environment due to excessively moist or dry air in the building.

Good, but not exceptional, thermal performance

Hempcrete is an insulation material, and as such its thermal performance is important. One of the primary difficulties in introducing hempcrete to the building industry is the vagary that currently exists around quantifying the thermal performance values of the material. A thorough literature review turns up 19 thermal tests on hempcrete conducted at research facilities around the world. The insulation ratings found by these tests vary widely, from R-1.25 per inch to R-2.3 per inch for low- (200 kg/m^3) to medium- (400 kg/m^3) density wall insulation mixes. Even mixes with the same density vary in the test results. To meet minimum code requirements of R-24 in much of Canada, these results could make the difference between needing a wall that is over 19 inches deep (488 mm) to one that is a more reasonable 10.5 inches (266 mm).

To compound the issue, several *in situ* tests have shown that the actual thermal performance of hempcrete walls is considerably better than the R-values would indicate. Hempcrete has some properties that are unique among insulation materials. As one very comprehensive test of hygrothermal properties of hempcrete states: "The reasonably low thermal conductivity of hemp lime, combined with phase shift, phase change effects, high internal thermal comfort, low initial energy transfer rates, passive humidity control and lower energy requirement for ventilation, all contribute to the reduction of [energy use]."[9] These aspects of hempcrete thermal performance will be explored in the Building Science Notes chapter of this book.

An average of all the test results of mixes in the 275 to 350 kg/m^3 range gives a value of R-1.9 per inch (requiring a 12.5-inch wall to reach R-24). The only North American tests performed to date have been at Ryerson University, and are summarized in the table shown here.

We build our hempcrete walls in the range of 12 to 16 inches (300 to 400 mm) wide for

Table 2.3

Mix and Density	Samples	"k" (W/mK)	"k"- Mean (W/mK) (± 5.00%)	Sample Thickness Mean		RSI (m^2K/W)	RSI Mean (m^2K/W)	R Imperial Mean	R/Inch Imperial (± 5.00%)
				m	inch				
1 (233 kg/m^3)	1	0.075	0.074	0.082	3.21	1.06	1.10	6.23	1.94
	2	0.073				1.13			
	3	0.075				1.10			
2 (317 kg/m^3)	1	0.088	0.088	0.081	3.20	0.91	0.92	5.24	1.64
	2	0.088				0.92			
	3	0.088				0.94			
3 (388 kg/m^3)	1	0.104	0.103	0.082	3.22	0.79	0.80	4.53	1.41
	2	0.106				0.77			
	3	0.098				0.83			

Source: Dhakal, Ujwal (2016) "The effect of different mix proportions on the hygrothermal performance of hempcrete in the Canadian context," graduate research project at Ryerson University, Toronto.

northern climate use (climate zone 6), and achieve actual performance results that exceed code expectations.

Fire resistance

Although the Internet is full of videos of people aiming blowtorches at hempcrete samples, there is not a great deal of certified testing done on the fire resistance of hempcrete walls. As the homemade videos indicate, the mineral coating of the lime binder around each piece of hemp hurd adds a high degree of flame resistance to the plant material.

A 2009 fire test was conducted by BRE Global in the UK to meet the BS EN1365–1:1999 standard.[10] This test subjected a 3×3 meter (10×10 feet) wall of hempcrete that was 300 mm thick (12 inches) to temperatures of 800 to 1,000° Celsius (1800° Fahrenheit), while also subjecting it to a vertical load of 135kN (30,349 lb). The test showed that the wall met all requirements for integrity, insulation and loadbearing capacity for 73 minutes. During this test, the mean temperature on the side of the wall unexposed to the flames stayed under 60°C (140°F), and for the first 15 minutes stayed under 30°C (86°F). This test was performed on a hempcrete wall with no plaster or other finish on the insulation, so real-world performance would be enhanced by protective plaster or other wallboard.

A Canadian fire test was undertaken in 2015 to ASTM E119-14 and CAN/ULC S101-07 standards. The test report concludes that "The test specimen successfully met the conditions of acceptance for a 68-minute Fire Resistance rating," and included a successful hose stream test.[12]

It is worth noting that the lack of chemical content in hempcrete means that the small amount of smoke generated has none of the highly toxic compounds generated when petrochemical wall insulation and components burn.

Good acoustic properties

There has not been a great deal of testing of hempcrete's ability to dampen sound transmission from outside the house or between rooms. In 2002, a test in the UK was performed on a pair of 6-inch (150 mm) walls with a 3-inch (75 mm) cavity between them, which is a standard arrangement for walls separating units within a building. The hempcrete walls offered sound reduction of 57 to 58 dB, exceeding the 53 dB code requirement.[11]

Who Would Want to Build with Hempcrete?

Currently, hempcrete is a material choice for owners and builders who wish to create a building with the following qualities:

- Low- or zero-carbon footprint
- Nontoxic materials and high indoor air quality
- Excellent moisture-handling properties
- Durability
- Fire resistance
- Good thermal performance and very stable indoor temperatures

In exchange for these positive qualities, the builder will face slightly higher initial material costs and additional effort to source the materials from non-standard channels.

Current trends in North America are toward carbon reductions, less toxic materials, moisture resilience and durability; a builder who establishes an early foothold in the hempcrete market is likely to be rewarded as more people make choices based on the qualities that hempcrete has to offer.

One of the key advantages of hempcrete over other natural insulation materials is that it fits well with conventional framing techniques, so although it requires a different installation process than conventional insulation, it does not necessarily require experienced builders to change their approach to framing. And the formwork used for installing hempcrete is a lightweight version of the formwork familiar to any builder who has worked with poured concrete. Forming hempcrete in a frame-walled building results in perfectly straight and flat walls, so that the aesthetic result also closely matches mainstream expectations.

In particular, hempcrete is a good choice for those who live in extreme climates, either cold or hot, and in places where humidity levels are high for sustained periods of time. The antimicrobial and antifungal qualities of hempcrete make it very stable and safe when highly loaded with moisture, and can help to prevent mold and deterioration in such conditions.

There is an underlying tension among hempcrete advocates between those with a do-it-yourself philosophy and those aligned with the companies that have proprietary formulations for hempcrete. There are some real advantages to working with materials that have been tested and developed by a company with some history and knowledge and customer support. At the same time, the materials are simple, straightforward and accessible to those who have a desire to formulate and mix their own hempcrete. There is no right or wrong tactic to take, and it is the aim of this book to cover both options fairly and thoroughly.

As the hemp industry begins to take hold in North America, there will be improved supply chains and reductions in cost that will make hempcrete even more attractive. Early adopters using the material today are helping to set the stage for an increase in the use of hempcrete in the near future.

Notes

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