Designing a Small-Scale Grain Harvester: A Tool for Urban and Peri-urban Growers

An Interactive Qualifying Project submitted to the faculty
of Worcester Polytechnic Institute in partial fulfillment of the
requirements for the Degree of Bachelor of Science.

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April 28, 2012

Abstract

This project is intended to help small-scale grain growers meet an increased demand for diverse, locally grown grains by designing a reaper-binder machine. To refine our prototype and final design, we worked closely with a three person review panel, made up of grain farmers and industrial designers. With this prototype, we hope to provide farmers nationwide with a way to harvest and bind grains on small plots of land in cities and along the periphery of urban areas.

Acknowledgements

The success of our project depended on the contributions of many individuals over the past eight months. We would like to take the time to thank all of those who have helped and supported us in this process.

First, we like to thank our advisor, Professor Robert Hersh for providing us with guidance and support through this long process. We would also like to thank our sponsor, Andy Pressman for providing us with advice and insight into all aspects of our project. He provided us with numerous contacts that helped us with our project. Final thanks go to Dorn Cox and Joel Dufour, for being part of our design review committee and giving us valuable information for our design.

Executive Summary

Background

Nationally, most of the food we eat is produced by large agricultural supply chains, which link farmers, seed suppliers, pesticide and fertilizer suppliers, transporters, distributors, wholesalers and retail outlets. Currently, the United States harvests about 114.8 million acres of grain per year worth some $15 billion (USDA Census of Agriculture, 2007). On a number of dimensions this scale of production is not sustainable. One of these issues is that $28 billion is spent by all the farms in the U.S. on chemical fertilizer alone, which is made primarily from non-renewable resources including fossil fuels (USDA Census of Agriculture 2007). On an average farm in the United States, 107 gallons of fossil fuels per acre will be used, with one third of that going into the production of fertilizer (Pimental, 2006). These chemical fertilizers, pesticides, and herbicides end up either on our food or into our groundwater, posing health risks to farm workers, nearby residents, and consumers (Groundwater, 2003).

An alternative to these large and distant supply chains, and reliance on chemical fertilizers and other inputs, is to grow food, such as grains, organically and closer to where it is consumed. Such interest in encouraging local and regional agricultural production is evident in a number of cities, such as Portland, Seattle, New York, Detroit and Philadelphia where community gardens are burgeoning, farmers markets are expanding, urban farmers are growing food on rooftops, vacant lots, in retrofitted warehouses, in backyards, and new value chains that connect small and medium size growers to markets are proliferating (Lovell, 2010).

Even though there is a growing trend to produce local, fruits and vegetables in cities and on the periphery of urban areas, local grain production remains limited. It is rare, for example, for locally produced grains to be used even in small craft breweries since most breweries buy malted barley from large malt houses in the Midwest at commodity prices; nor is locally grown grain typically found in farmers markets since farmers typically get greater profits from selling fruit and vegetables. One barrier to expanding the market for locally produced grain is the lack of appropriate machinery to harvest grain grown on a small scale (C. Stanley, personal communication, 11/12/2011).

While these small-scale grain harvesters exist in Europe and parts of Asia, farmers do not import this machinery into United States because of exorbitant transportation costs. To harvest grain, small-scale farms either rent a combine harvester or use hand tools, such as a scythe or sickle (Pitzer, 2010). Neither technology is suitable for small-scale grain production. Combine harvesters are too large and cumbersome for this scale, and would be next to impossible to maneuver in an urban farming environment. Hand tools may work for less than a half an acre, but if there are multiple small plots, it would be a very labor intensive and time consuming job. What is needed is an appropriately scaled machine that could be used by growers to reap and bind grain grown on a few acres.

The goal of this project was to help small-scale growers meet an increased demand for local grains by designing a reaper-binder machine to harvest grains more efficiently. We interviewed small-scale growers and agricultural engineers to identify the current problems with growing grains in New England, to learn about the types of machines currently used to harvest grains, and to develop appropriate design criteria for our product. Once we designed a three-dimensional computer model, we worked with a three person review panel to refine our ideas. With this design we hope to provide farmers with a means to harvest and bind grains on small plots of land and in broader terms develop urban and small-scale agriculture.

Findings

Our team determined that the best machine to harvest a small scale plot of grain is a reaper binder that attaches to a two-wheeled, walk behind tractor. The basic steps taken in growing grains are planting, harvesting, binding, threshing, cleaning, and milling. The machine we designed handles the harvesting and binding aspects of farming grain.

Through our interviews, we found that developing an attachment for a two-wheeled tractor would be the most practical solution. This would provide farmers with a simple platform that only requires farmers to purchase the necessary attachments. Based on our interviews with our sponsor and Joel Dufour, we assumed that most commercial farmers would be willing to spend up to $8,000 dollars for a machine to harvest grains (J. Dufour, personal communications, 11/10/2011). Subtracting the cost of the base tractor, which has a minimum price of $1,587 and a maximum of $5,899, we estimated the budget for materials and labor would be about $6,500 or less for our attachment (see Appendix B: Cost Report).

We came up with an initial design that used a sickle bar cutter and two channels to feed the grain back to the binder. We then sent this design to our review board that provided feedback. This review board included Andy Pressman, who is our sponsor for this project, Dorn Cox, an innovative farmer from New Hampshire, and Joel Dufour, who owns Earth Tools Inc., and sells BCS tractors. After we received comments from our design board, it was decided that we should start our design from the beginning again. For this redesign, we used the BCS 622 reaper binder as a base for our design in order to eliminate some of the problems that we encountered when we were utilizing the existing sickle bar attachment. One of these problems was the grain had to be diverted two separate ways because the existing sickle bar mower's body was in the middle. Thus, the cut stalks of grain needed to go to the right and left of this body. For our redesign, we decided to make our own sickle bar cutter so that there would be no need for separate channels.

The first step our redesigned machine will take in harvesting grains will be to cut the stalks of grain with the use of oscillating blades at the front of the machine. Once cut, the grain will be brought to the center of the machine by finger-like appendages. These feeding fingers will also be powered by the PTO output of the tractor and feed the stalks of grain into the middle of the binder to be bound. These fingers also serve the purpose of compacting the grain into the binder as well as keeping the stalks of grain upright. This way more grain will be bound in each bundle, thus increasing efficiency. The feeders were designed so that one feeder would be at its center-most position while the other would be at its furthest position away from the center of the machine. This way, they reach the center of the binder at alternating times, maximizing the amount of grain that can be brought and compacted into the main channel. With this alternating movement, any collisions would be avoided between the two feeder arms.

The two wheeled tractor will be connected to the binder at the back left-hand side (viewing the machine from the front). The reason we chose this location for the placement of the tractor was so the bound grain would fall and land to the left of the driver. If the tractor had been placed in the middle, the bundles of grain would need to be diverted to one side or the other after they were bound. This could potentially cause problems if the bundles were dropped into the uncut stalks of grain. With the design we created, the bundles of grain would fall in the center of the cutting path of the machine thus reducing the chances that the bundles of grain would fall into the uncut stalks.

The binder mechanism for our design is located at the end of the channel. Before any grain reaches the tying mechanism, twine will be strung across the opening. The free end of the twine is held on the tying side of the machine by a rotating disk. This piece of twine will hold the stalks of grain until there was enough to be bound. The rotating twine clamp will be powered by a small motor that will be timed with the rest of the tying mechanism. The location of the arm is located at a position so the grain will not fall over as it is being bound. When the bundling area is filled to capacity, an arm that has the twine running inside it moves across the channel and encompasses the stalks of grain with twine. This rod is powered by a slider and bar linkage driven by gears. At the other end, a mechanism would tie and cut the twine, thus forming a complete bundle. This mechanism consists of a hook that rotates around and creates one loop of twine. At a point along the rotation, a jaw that is hinged on the hook, opens and then closes, grabbing the two ends of twine.

There is a metal loop above the hook that is used to help create the loop. At the same time, a blade cuts the twine that was brought by the arm and held in place by the disk and the hook rotates, pushing the loop of twine over the top of the two newly cut ends thus forming a knot. The tying arm would then retract back to the other side, drawing the twine back and the process would start all over again. The newly bound bundle will then be pushed off the back of the attachment by newly cut grain.

Guards were placed on the undercarriage of the binder in order to protect the gears and axles. Another guard was placed in the channel to protect the rotating hook from catching any of the stalks of grain. This reduces the chances that debris will kick up and damage the gears. We determined that this design satisfied most of our parameters that we had specified.

Conclusions and Recommendations

From our interviews with grain farmers and distributers, we learned that while there is no suitable small-scale grain harvesting machines available to growers in the United States and there is an emerging need for a cost friendly machine that could efficiently harvest grains on a small-scale. There are a few different potential end users that could benefit from our reaper-binder. The first would be a current farmer who grows grains on one to two acre plots. This could include multiple lots in need of portable equipment like our grain binder. Our product could also be used by urban farmers collectively. They could buy the reaper-binder communally thereby reducing upfront costs.

Even though our project only focuses on the grain bundling aspect of small-scale grain growing, we researched other aspects as well. After grain is harvested, the threshing process can begin. Threshing is done to the bundles to remove the seeds from the chaff. This process is normally done by hand, which is a very inefficient, laborious process. After talking with a few of our contacts, we recommend buying or building a small machine similar to John Howe's thresher/winnower device that he has created (Northern Grain Growers, 2011). This machine efficiently separates the seeds of the grain from the chaff by sending it over a screen with force. The seeds fall through the holes in the screen. Once separated, the seeds can be processed further towards consumption.

During our design process, there were some aspects that could have been further refined if we had more time. Future research should focus on the timings for the tying mechanism and the tying arm. In our design, they are both driven off the feeder arm axle, which means the tying mechanism is moving constantly regardless of the amount of stalks ready to be bundled. The design would be improved if the timing mechanism only engaged when it was triggered by a full bundle. Another area that needs further research is the ability to cut grains at different height. Depending on the type of grains grown, the cutting height will vary. By designing a machine that can have variable cutting heights, a farmer will be able to grow a wider variety of grains. Most likely other small unknown issues would be found and fixed if a prototype were built and further time was spent on design and testing. This was not able to be done due to the time constraints of our project and lack of resources. Ideally, other designers will look at our model and determine a plan for the manufacturing of our design. After that, a prototype will be built and tested to see if there are any issues that need to be worked out. After a couple iterations, we hope, the binder could then be sold in the market.

Contributions

Christopher Boyle
Chris was the primary writer of the conclusion chapter and wrote sections in the background and results. He also was one of the primary editors of the paper. Chris also provided feedback and help to the design process of our machine.

Ian Jutras
Ian was the designer behind both revisions of the reaper-binder design. He also wrote a large section of the results section, as well as sections in the background, methodology, and introduction. He also was a primary editor of the paper. Ian also recorded interviews as well as helped in our final presentation video.

Christopher Molica
Chris wrote a large section in the background and methodology. He also edited parts of the paper. Chris also contributed a lot to the development of presentations. He created and managed our website.

Earl Ziegler
Earl wrote section in the introduction, background, and methodology. He also edited parts of the paper. He contributed with the content for the presentations. Earl along with the rest of the team conducted personal interviews.

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Chapter 1: Introduction

Nationally, most of the food we eat is produced by large agricultural supply chains, which link farmers, seed suppliers, pesticide and fertilizer suppliers, transporters, distributors, wholesalers and retail outlets. Currently the United States harvests about 114.8 million acres of grain per year worth some $15 billion (USDA Census of Agriculture, 2007). On a number of dimensions this scale of production is not sustainable. One of these issues is that $28 billion is spent by all the farms in the U.S. on chemical fertilizer alone, which is made primarily from non-renewable resources including fossil fuels (USDA Census of Agriculture 2007). On an average farm in the United States, 107 gallons of fossil fuels per acre will be used, with one third of that going into the production of fertilizer (Pimental, 2006). These chemical fertilizers, pesticides, and herbicides end up either on our food or into our groundwater, posing health risks to farm workers, nearby residents, and consumers (Groundwater, 2003).

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Chapter 2: Background

The goal of this project is to help small-scale farmers in Southern New England meet an increased demand for local grains, by designing a reaper-binder machine to harvest grains more efficiently. In the following section we will discuss the history of growing grains in the New England area, focusing on small-scale farms. We will then consider recent trends concerning farming in Massachusetts. In section 2.2 we provide an overview of opportunities for small-scale grain growing. And finally, in section 2.3, we examine the grain growing process as well as the lack of suitable harvesting equipment.

2.1 Grain growing in New England

In the past, the state of Vermont and the Connecticut River Valley were known as the "Bread Baskets" of New England. Vermont alone had the capacity to harvest about 40,000 acres of wheat a year during the 1850's (Matheson, 2009). As America expanded west, so did New England's agricultural primacy in cultivating grains. Farmers moved to the Midwest to take advantage of more fertile soil and more consistent weather (Matheson, 2009). Historically, the infrastructure located within New England included places to both clean and mill grain. However, these industries shut down when grain growing moved west (Koenig, 2010). As a result, there are fewer locations to store and mill grains in New England today (Matheson, 2009).

The shift of grain production to the west meant that the land previously used for growing grain was not needed for food production and was developed for other end uses, primarily new housing (Larkham, 1992). This resulted in a steady decrease, as shown in the graphs below, in the amount of farm land in Massachusetts. At the turn of the 20th century there were about 3,000,000 acres of farmland in the Massachusetts. By 2007, this number had declined by 85 percent, amounting to roughly 500,000 acres. During this time, the total number of farms in Massachusetts also dropped from around 37,000 farms to only about 7,700. However, over the past 20 years, this number has been steadily increasing, suggesting growing interest in farming in Massachusetts (USDA Census of Agriculture, 1850-2007).

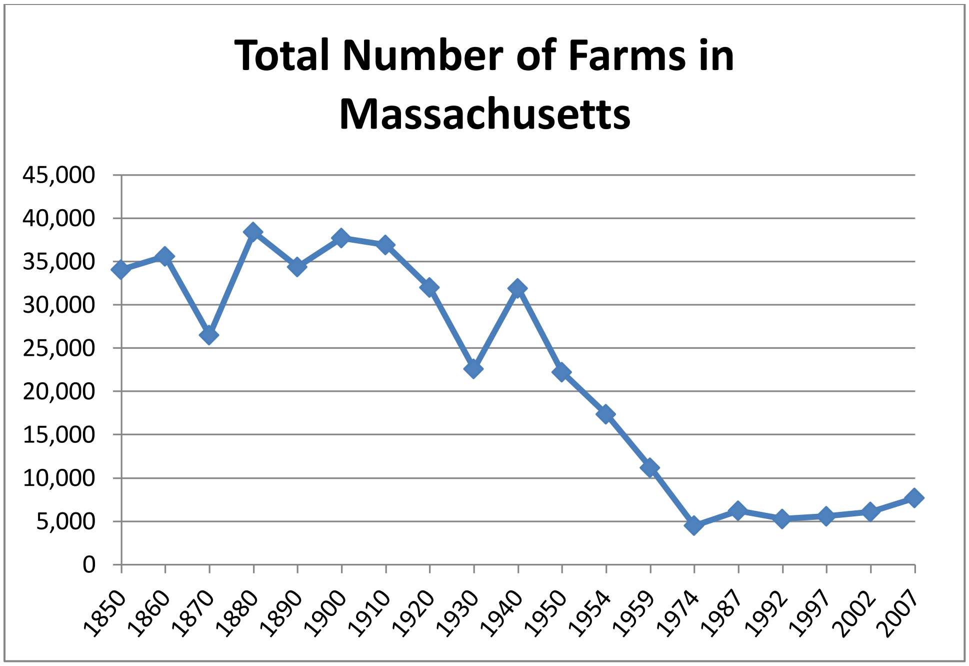

Figure 1: Total Number of Farms in Massachusetts 1850-2007

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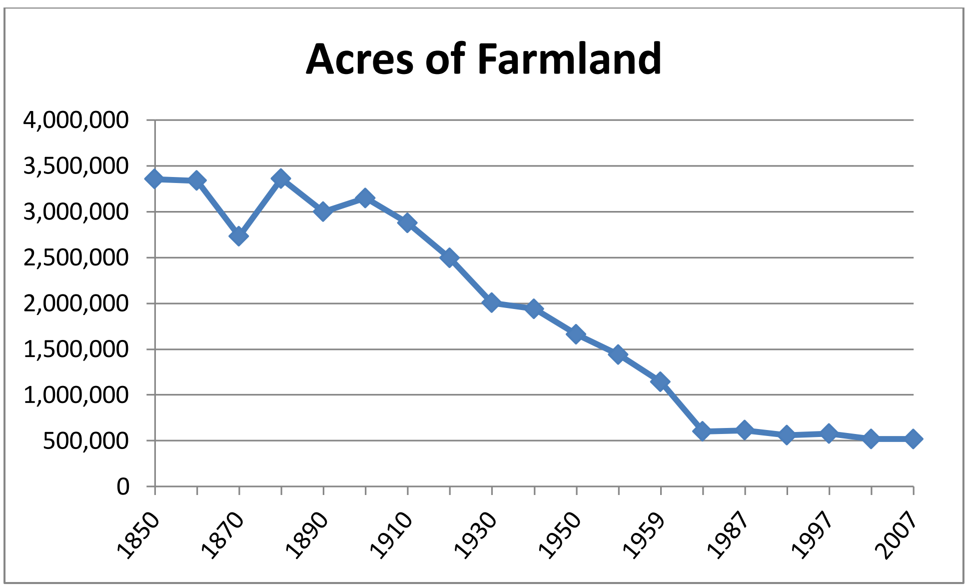

Figure 2: Total Acres of Farmland in Massachusetts 1850-2007

Over the past 30 years, as depicted in Figure 3 below, the number of farms in Massachusetts that are less than 9 acres in size has increased by over 250% from about 650 in 1974 to over 2,000 in 2007 (USDA Census of Agriculture, 1850-2007).

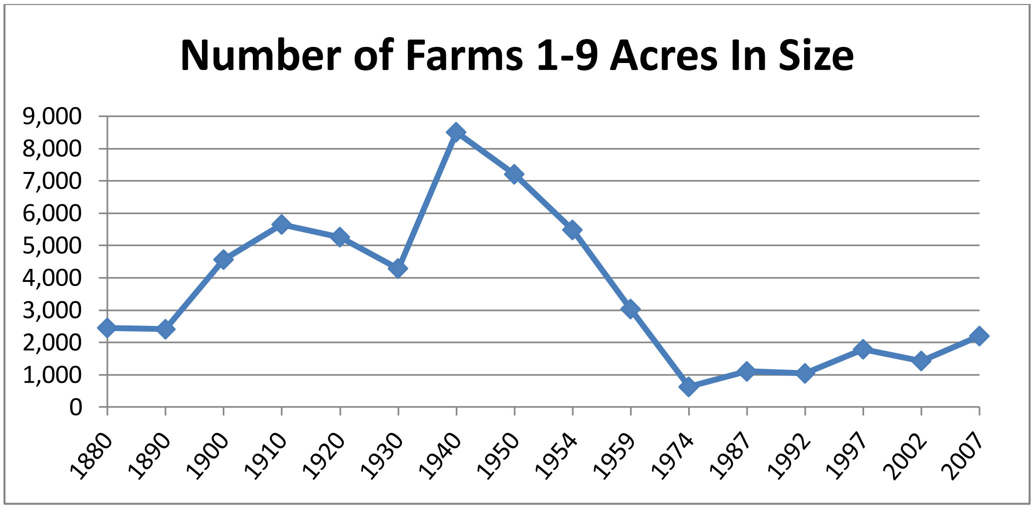

Figure 3: Number of Farms 1-9 acres in Massachusetts 1880-2007

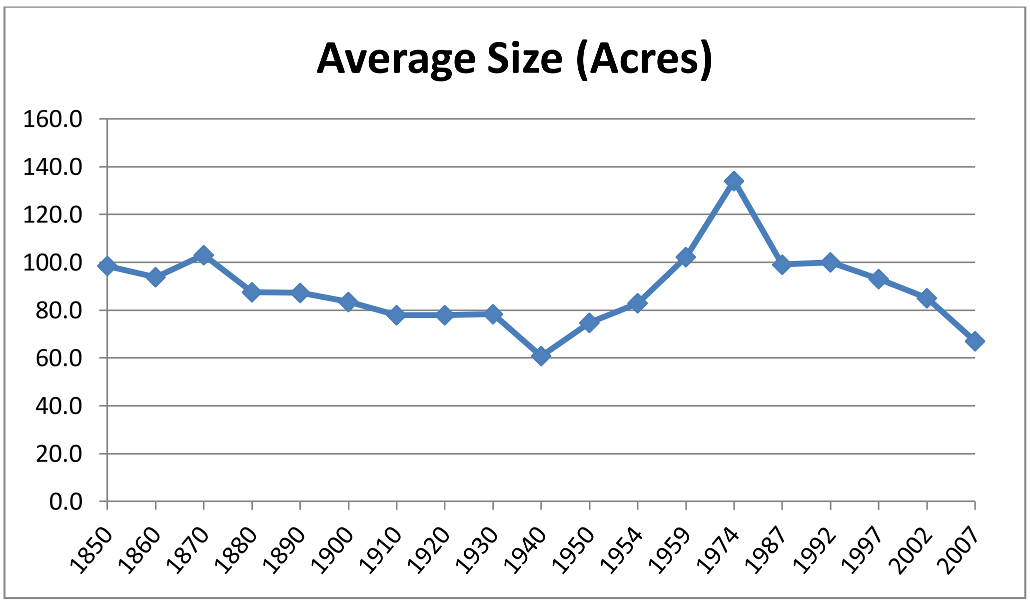

Figure 4: Average Size of Farms in Massachusetts 1850-2007

However, this expansion in small-scale farming in Massachusetts over the past thirty years has not translated into increased grain production. In 2007, only twelve of the 7,691 farms in Massachusetts grew grains (USDA Census of Agriculture, 1850-2007). However, there has been a growing demand for locally produced grains, including millet, rye, spelt, and buckwheat during the past five years (Erickson, 2011). This is due, in part, to the local food movement in which consumers are looking to support local farms and purchase fresh local produce (Rathke, 2011). There is also a new interest in preserving heritage grains and maintaining a variety of different grains in order to maintain genetic diversity as well as preserve the complex flavors associated with them (Koenig, 2010). People are becoming interested in local grain because of its greater nutritional values. Traditional bleached white flour has less nutritional value because it needs to be processed in a way that allows it to be shipped and stored for long periods of time without spoiling (Wight, 2011). The less the grains are processed, the higher the nutritional value of the grains and related products become (Wight, 2011). Although New England's grain production is unlikely to reach that of the 1850's, grain farming in the region is steadily increasing (USDA Census of Agriculture, 1850-2007)[1].

New England's unpredictable climate has a major impact on both the types of grains that can be grown during different seasons and on the yields (Darby, 2010). In New England, farmers must take into account inconsistent weather from year to year which, according to one of the farmers interviewed for this report, is "generally too damn wet" (C. Hatch, personal communication, 10/25/2011). This wet climate increases the chance that mildew and rust will form on the grain (Powell, 2008). New England farmers see climate as a major limitation and compensate for these conditions by growing specific types of grains during each season. For example, farmers grow oats in the spring because of its adaptability to cool and moist conditions, and during winter months, winter triticale has had varying success (Darby, 2010). However, Darby also states that wheat is a versatile crop which can be used for both the spring and fall seasons (Darby, 2010). The varying weather conditions throughout each season affects New England grain growers, and limits the grains that they can grow.

2.2 Opportunities for Small-Scale Producers

Consumers, urban farmers, public health advocates, city planners, community groups, nonprofit organizations and others are trying to reintegrate food production into urban environments in many ways. This initiative is opening opportunities for small-scale growers to start farms in and around urban areas. The rising number of farmers markets in the United States, shown below, suggests that there is renewed interest in locally grown food.

[1] According to US law, any farmer or rancher who produces more than $1,000 worth of agricultural products in a given year, must respond to the agricultural census (USDA).

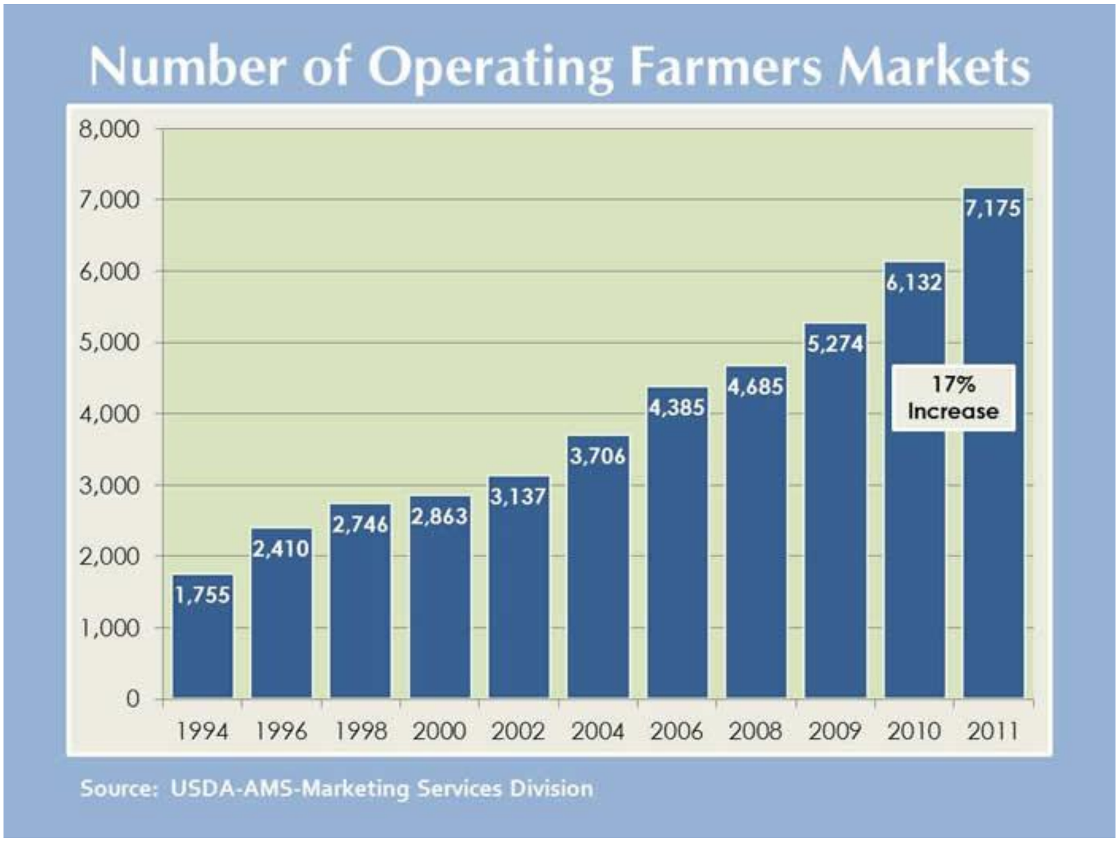

Figure 5: Farmers Markets in the United States over 11 Years[2]

One city that is on the front of this new trend is Chicago. The Chicago City Council approved a new zoning code in 2011 that allows for extensive urban agriculture in the city. This code allows community farms to be up to 25,000 square feet. The amendment also relaxes limitations on fencing and parking which reduces costs that entrepreneurs and organizations have to pay in order to maintain their farm (Office of the Mayor, 2011). By reducing these costs, the city is making urban farming more enticing to small-scale farmers. This new zoning code also helps by turning unused lots into urban gardens which can provide jobs and fresh produce to the residents in the city.

Another city experimenting with urban agriculture is Philadelphia, Pennsylvania. The city has created a Food Policy Council to develop a plan for bringing local food within ten minutes of seventy five percent of its residents (Greenworks Philadelphia, 2009). This means

[2] Picture obtained from http://www.ams.usda.gov/AMSv1.0/ams.fetchTemplateData.do?template=TemplateS&leftNav=WholesaleandFarmersMarkets&page=WFMFarmersMarketGrowth&description=Farmers%20Market%20Growth&acct=frmrdirmkt

that the city is increasing their urban food production and the number of food markets so that most residents only have to walk ten minutes to obtain locally grown food. There are currently 30 farmers markets and 200 food-producing gardens providing local food to the residents of Philadelphia. This is not enough however, to support all of its residents. In order to help solve this problem, the city is planning on adding 59 food producing gardens as well as 12 farms and 15 more farmers markets to Philadelphia. To help encourage demand for locally grown food, universities and hospitals have created a number of local food purchasing programs (Greenworks Philadelphia, 2009). There also has been a proposal set forth to the city in regards to new zoning rules to allow commercial farming (Greenworks Philadelphia, 2009). This would allow more farmers to grow grain in an urban environment. The Mayor's Office of Sustainability is working to promote the urban farming industry and trying to create more jobs connected to urban farming (Greenworks Philadelphia, 2009).

Perhaps no city is promoting urban agriculture as much as Portland, Oregon. Like Philadelphia, Portland also established a Food Policy Council in 2002 which helped devise the Diggable City project. This project assesses and turns public land into different forms of urban agriculture (Lovell, 2010). As of 2005, 30 community gardens were up and running, and were able to generate about a half of a million dollars in produce each year. The demand for new community gardens is extremely high as there was a three year wait list for families to acquire a plot (Hess, 2005). The city also purchased a former dairy farm that is now being run by farmers. Part of this farm is being used as a community supported agriculture site (CSA) (Hess, 2005). A CSA allows residents to buy a "subscription" from a local farmer in which they get fresh produce from the farmer in return. This produce includes whatever is in season at that point in time (What is a CSA, 2006). Also in Portland, landowners are donating their unused yard space to entrepreneurial businesses to be used for growing produce. In return, the landowner receives some of the produce and the rest is sold through CSA or farmers markets.

Such a program is the basis for a new business model in Boulder, Colorado.. Through a program called Community Roots, local homeowners can turn their yards into a food producing garden. The program has acquired about a dozen properties in a few neighborhoods and grows produce such as lettuce, spinach, and kale. In return for donating their land, the homeowners can pick and eat some of what is grown. Like in Portland, the rest is sold through Community Root's CSA and the Boulder farmers' market (Beatley, 2011).

A recent trend to encourage entrepreneurs to become involved with urban and peri-urban agriculture is SPIN Farming, or small plot intensive farming. SPIN Farming is where available plots, such as vacant lots and backyards, are leased to a private contractor or farmer and are used to grow grains or other produce. This strategy utilizes techniques that maximize the space available as well as the profit (Spin Farming, 2012). In some cases the current owners or growers of these available plots would get together and purchase the machinery needed to produce grains cooperatively (Urban Agriculture, 2001).

2.3 The Grain Growing Process and Lack of Appropriate Small-Scale Grain Equipment

Grain farmers operating at any scale will need to have equipment suited for the different growing processes of which the main ones can be seen in Figure 6. The first step in growing grains is preparing the land for planting. This involves tilling the soil, a process that provides nutrients by loosening the different layers as well as incorporating air into the soil. To plant the seeds, a farmer can either plant the grain by hand, or utilize a broadcast seeder to disperse the seeds and provide an even coverage (Pitzer, 2010). A seeder is one of the few mechanisms used for planting grains accurately on multiple rows at the same time allowing farmers to use a fewer number of seeds and still achieve a high product yield. Seeders are available in an assortment of sizes and can be used on both large and small-scale farms and are readily available in the United States.

Figure 6: A Flowchart of the Grain Growing Process[3]

Once the grain has fully matured, it must be harvested. This involves cutting down the stalks of grain using a cutting mechanism and gathering them into bundles. Farmers have multiple harvesting practices depending on the size of their plot of land. A large farm harvests grain with either a large harvesting machine or a combine harvester (Damodaran, 2007). These machines can cost over $250,000 per machine (John Deere, 2011). For a farm under two acres, a farmer usually harvests grain with a scythe or sickle (Pitzer, 2010)

[3] Pictures obtained from
http://2.bp.blogspot.com/-eQDXYNVa_10/TiQ1v93mCaI/AAAAAAAAAg8/EsOtHk34-LE/s1600/Planting-seeds.jpg
http://mypeoplepc.com/members/jjgomez//sitebuildercontent/sitebuilderpictures/grdnbeangrwngnrmalilustration.jpg
http://www.economy-ukraine.com.ua/wp-content/uploads/2011/07/Harvesting-Grain.jpg
http://3.bp.blogspot.com/-ZzC0KirXi4I/TtxE5ZmSs3I/AAAAAAAABnI/b7ibmssqwPI/s1600/Proshika+2.jpg
http://u.jimdo.com/www39/o/s9d58ccb3f18d0300/img/ifeee9e9f536bed50/1321495173/std/image.jpg
http://image.lehmans.com/lehmans/Images/products/main/525.jpg
http://madeleinerex.com/wp-content/uploads/2011/03/Bag-of-Flour.jpg

Figure 7: Close Up of a Sickle[4]

Harvesting by hand can be a slow and tedious process, but it remains the cheapest way for small-scale growers. Once farms reach two or more acres in size however, hand-tools become impractical, forcing farmers to utilize a range of mechanical harvesting equipment. Currently, new farm equipment in the United States for use on farms less than two acres is difficult to obtain because companies are not manufacturing machines for that scale of production. This is due to the fact that at this time there is no large demand for small-scale machinery. (A. Pressman, personal communication, 12/14/2011). BCS America offers a wide variety of two-wheeled tractors. For most farmers producing on two to five acres, these tractors are reasonably priced (A. Pressman, personal communication, 12/14/2011). However, these tractors only include a cutter bar attachment, and do not have the capabilities of a larger combine. For farms larger than five acres, these machines are considered to be inefficient, as it would be very tedious and time consuming to harvest grain. In the absence of new, appropriate sized grain harvest machines, small-scale farmers today are still using equipment from the middle of the 20th century because that is all that is available (S. Normanton, personal communication, 10/18/2011).

After the grain is harvested, farmers proceed to threshing the grain. At this stage, the grain is removed from the straw and chaff by hand or with a threshing machine (Pitzer, 2010). Afterwards, the grain needs to be removed from the lighter chaff that is still intermixed with the grain. In the case of a really small farm, this can be done by using a small window fan or wind

[4] Pictures obtained from
http://www.buymeposters.com/product/1008848/close-up-of-the-hands-of-an-egyptian-farmer-harvesting-wheat-with-a-serrated-sickle.php

power (Pizter, 2010). Larger farms use a combine harvester that have a series of screens as well as a fan to separate the grains from the lighter chaff (Modern Marvels: Wheat, 2008). Once the grains have been separated, they must be cleaned and protected in containers from moisture, light, heat, and rodents which would ruin the grains. Small amounts of grain can be stored in bags in a freezer, while larger amounts can be stored in large metal or plastic buckets with lids (Pitzer, 2010). Milling is the last stage of the grain growing process. At this stage, the grain is ground into a powder form and is ready for consumers to use.

Mechanical Grain Growing Limitations

A major limitation for current and potential New England grain growers is the lack of appropriate and affordable small-scale grain equipment. In the United States, the current grain equipment sold is designed for large-scale farms only (John Deere, 2011). The large-scale equipment on the market is impractical to store or transport on a small-scale site. Also, the larger machines are difficult to clean out, and as a result mix products from previous harvests when dealing with multiple plots (C. Stanley, personal communication, 10/12/2011). This is a major problem for small-scale grain growers who share a large scale machine as a large portion of their crop would be lost, and mixed into the next farmer's harvest (C. Stanley, personal communication, 11/12/2011). According to our initial interviews with farmers, the needs of small-scale farmers greatly differ from those that grow wheat on a large scale, and the tools that they use are not interchangeable.

Figure 8: 1958 Combine Harvester[5]

[5] Pictures obtained from
http://goo.gl/iAHw9

This limits New England small-scale farmers to using either older grain machinery or importing machinery from overseas. Pictured below are some of the machines that farmers currently use today. Some farmers use grain equipment which was developed in the United States around the 1950's. These machines can be purchased for prices ranging from $1,500 - $7,200. This equipment was designed for smaller plots of land, and fits the needs of small-scale farmers well. However, this machinery is no longer manufactured, and is more difficult to come by. Another limitation of the older technology is that when it breaks, it is up to the user to fix it, which usually includes manufacturing a new part by hand (J. Dufour, personal communication, 11/10/2011).

The other option for small-scale farmers is to import small-scale machinery manufactured in other countries. The cost of importing this equipment alone would be out of the price range for most small-scale farmers (A. Pressman, personal communication, 12/14/2011). Reaper-binders like the Mitsubishi Reaper-Binder are both expensive (costing over $9,200) and slow, harvesting only a fifth of an acre an hour. Due to these limitations, a majority of small-scale farmers cannot find an appropriately scaled harvester. Small-scale farmers need a machine that can harvest several acres within a few hours. This machine must also limit the loss of grain.

					
	John Deere Combine	**Mitsubishi Reaper-Binder**	**BCS Reaper-Binder**	**20th Century Used Combine**	**Scythe**
Price	$250,000	$9,200	$ UNKNOWN	$1500-7200	$17
Acres Per Hour	20 acres/hour	.21 acres/hour	1 acres/hour	5 acres/hour	.125 acre/hour
Waste	1.5%	~0%	~0 %	1-3%	~0 %
Limitations	Very expensive and inefficient for a small-scale farmer	Very slow and needs to be imported	Engine does not meet EPA standards	Inefficient startup and has high maintenance costs	Very slow

Table 1: Various Grain Harvesting Machines and Qualities[6]

[6] Pictures obtained from
http://absolut-toys.com/image/cache/data/Bruder/02132-500x500.jpg
http://img.diytrade.com/cdimg/130272/22584725/0/1311726458.jpg
http://www.bcs-ferrari.in/about.html
http://scythesupply.com/

Chapter 3: Methodology

In view of the renewed demand for local grains, our goal is to design an affordable, grain reaper-binder to help small-scale farmers more efficiently harvest their grain. The objectives we identified to accomplish our goal were:

1. Identify and interview local grain farmers and grain growing associations to learn more about current production and harvesting practices, grains produced, and emerging trends in local grain production.
2. Identify and interview farm equipment manufacturers and farmers who have built grain harvesters, in order to determine the current products available for our scale and research their current designs.
3. Conduct archival research and review patents on small-scale combine harvesters, binders, and threshers from the past.
4. Design our own grain reaper-binder.

This chapter will discuss in detail the procedures and methodologies that we used to design our product and accomplish these objectives.

3.1 Conducting Interviews with Grain Farmers and Grain Associations

We interviewed grain growing associations and small-scale grain farmers in the New England area. We first contacted grain associations in the northeast. Since many of the associations deal directly with a large number of farmers, we were able to obtain a wide range of information regarding common machinery used, climate problems in New England, and contacts of grain farmers in New England. Contacting with these associations was primarily through e-mail, followed up with telephone calls. Some of the major questions for grain associations included:

- What types of equipment do farmers use to harvest grain now?

- Our initial research suggested there is an increased demand for local grains in New England, to what extent is this true?
- What are the reasons for this increased demand and what opportunities are there for small scale grain farmers?
- What are the major challenges to expand the grain farming industry in New England?

The responses for these questions were collected in two excel documents: one including responses from our interview questions, the other listed any additional contacts gathered from these email surveys and phone calls.

Next, our group conducted email interviews with farmers. This approach helped initiate a line of communication with local farmers. Since only a few farmers grow grain on a small-scale in our local area, our team contacted these farms individually. The following is a list of farms contacted:

1. Living Earth Farm, Rutland, MA
2. Many Hands Organic Farm, Barre, MA
3. Overlook Farm, Rutland, MA
4. Valley Malt, Hadley, MA
5. Upinngill, Gill, MA
6. Four Star Farm, Northfield, MA

The farmers that work on these farms above served as advisors, providing information regarding old grain farming practices which related to the emerging movement of small-scale farming. Also, farmers could use their experience farming on a larger scale to provide insight into developing machinery for farms less than an acre. To find farmers, we initially searched for local grain farmers online. Other contacts were provided by our sponsor. During our interviews, we asked if they could provide us with additional contacts. Our key interview questions included:

- What is a good budget for a small-scale reaper-binder?
- Do you buy/share machinery through a co-op? What are the advantages/disadvantages?
- Would you want to share machinery with other local farms?
- What types of grains do you grow?
- What type of equipment are small-scale farmers using now?

- What is the average acreage of the grain production?
- What are some limitations to growing grain in New England?
- To whom do you distribute grain?
- Do you have plans to expand grain production? If yes, why? If no, why not?

These telephone interviews were conducted throughout the months of October and November. We wrote up key points from the interviews and developed follow-up questions. This data helped us determine whether or not a visit to their farm would help us with our project. The quantitative data from our email questionnaire was collected in an Excel spreadsheet that served as a table to organize the data received. The questions asked were collected in one column and the farmer's names were along the top row of the spreadsheet. This allowed us to see all our data at once and average the numerical data. The data collected helped develop the design, costs, and other further questions.

When we had further questions or could not reach farmers with e-mails, we called the farmer owners. Each call was conducted as a conference call loosely scripted to help solicit viable information from all our intended sources. Conference calls were conducted using the application Google Talk and were recorded using ScreenFlow with approval from the interviewee.

We also interviewed seven farmers who have built small grain machines or modified existing machines to better suit their needs. We asked the following questions in these interviews:

- What are the reasons you developed or modified your grain harvesting equipment?
- What were the critical parameters for your design?
- How did you develop a prototype from your design? If you have created your own product, do you have a patent on it?
- What were your cost considerations and how much did it cost to build your product?
- What problems did you encounter in designing and building your own machine? What advice would you give someone who was trying to develop a new machine?

The purpose of talking to these innovative farmers was to gain as much help and information as we could in developing our own grain reaper-binder and thresher as well as understanding why farmers create their own equipment. From the interviews, we were able to determine different ways to design our machine.

3.2 Interviewing Farm Equipment Manufacturers

We conducted informal interviews with farm equipment manufacturers such as Earth Tools Inc., BCS America, and Ferrari Tractors to determine what products are on the market right now for grain farmers in the United States. We contacted both the sales managers and engineers within each company. This helped us understand what machines farmers use to produce and harvest grain, as well as why they do not sell a small-scale grain combine or a reaper-binder in the United States. Talking to the designers helped us to determine whether or not our designs were feasible. We also tried to obtain average price values for small-scale machines that they currently sell overseas.

In order to figure out what is being done by these manufacturers, we asked the following questions:

- What type of equipment is available to harvest grain?
- On what size farms would that equipment typically be used?
- Why are there no small-scale grain combines or reaper-binders manufactured in the United States?
- Do companies contact farmers for design recommendations when designing new equipment?
- What is the process a company goes through when moving from a design to a prototype?

We conducted these interviews in the months of October and November. While conducting the interviews, we used Microsoft Word to take notes and record their responses.

3.3 Archival Research

To consider how past designs for small scale grain harvesters may be applicable to our project, we examined databases such as Google Patents, Google Scholar, Engineering Village, and Summon. The purpose of this research was to determine the types of equipment farmers in the New England area used to harvest and thresh their grains, differences in design and materials used, and if any past designs might be applicable to our project.

After finding useful patents, their associated patent number was further researched to gain more insight into the design. This was then used to develop a list of equipment used previously in the New England area. Using these older patents we were able to adapt some of their ideas into some of our own. We divided the search criteria among three sections:

- Size

  Would the size of this device accommodate small-scale farmers?

- Date Patented and Implemented

  Since our design is dealing with small-scale agriculture, looking into older patents may be more relevant since farms were much smaller. We will use these criteria to eliminate any patents.

- Cost

  These criteria will be applied to archival research to determine the most relevant devices.

3.4 Designing Our Machine

We used the data that we obtained from the interviews and research to help create the specifications of our grain machine; this included general size and functionality. We discussed our preliminary concepts and specifications with our sponsor and farmers that have extensive knowledge with small-scale grain equipment. Next, we developed some of the more practical designs. During this phase we contacted BCS America, our sponsor, and farmer contacts to acquire advice for both the farming functionality and mechanical sides of this design. This helped ensure that our design was fully functional and meet the farmer's needs.

In order to aid in the designing of a grain binder, we needed to have software that is capable of turning our ideas into an actual design. We chose the SolidWorks software as the best tool to design our machine. SolidWorks is a computer aided design (CAD) tool which allows for intuitive 3-D design and improved collaboration (Solidworks.com, 2011). We decided to use this software because our group members are familiar with it or have used it extensively. This enabled us to model our machine without having to spend time learning the software.

Design Review Committee

We then needed feedback regarding our design's ability to meet our goals. We accomplished this by forming a review committee, which could reliably critique our design from all areas. Our review committee consisted of Dorn Cox, a farmer from New Hampshire, Joel Dufour, the owner of Earth Tools Inc., and our sponsor Andy Pressman. The reasoning behind having these three individuals critique our design was to get varied opinions. We chose Dorn for his farming background and familiarity with machinery. Joel was able to cover the more technical aspects of the design and as a distributor of BCS machinery we hoped he would also be able to provide critical input about its manufacturability. Andy viewed the project in terms of feasibility, and oriented our design towards the target consumer, the small scale grower. Based on their comments, we revised our design.

Chapter 4: Findings

Our team has determined that the best machine to harvest a small scale plot of grain is a reaper-binder that attaches to a two-wheeled, walk-behind tractor. In this chapter we will present our detailed findings in three main sections. The first section focuses on reasons for emerging interest in small-scale growing, the need for a small-scale machine, and other such machines that are available elsewhere but not able to be imported. The second section looks at the parameters that are needed in a small-scale binder, as well as our initial design and the limitations involved. The last section concentrates on the feedback we received from our review committee and our redesign.

4.1 Small Scale Grain Production Trends

Finding 1: Grain growing is currently limited in the New England area; however, the demand is rapidly growing for many reasons.

There has been a growing interest in local grain from bakers, brewers, and consumers (Erickson, 2011). New England bakers have had an interest in local grain growing initiatives. Bakeries like Bread Euphoria in Haydenville, MA have used locally grown grains for nearly five years to make specialty breads (Powell, 2008). In addition, Hungry Ghost Bread in Northampton, MA began the Wheat Patch Project, which asks volunteers to grow an assortment of grains on their personal lawns and is then used in the bakery's bread (Powell, 2008).

There are others factors encouraging more local grain production. With rises in wheat prices, nearly tripling since the winter of 2007, consumers have looked toward local grain growing initiatives as a new source of grains (Powell, 2008). Interest in genetic diversity and a safe local food supply has also created a local demand for grain growing initiatives. While New England's grain growing infrastructure is limited due to lack of machinery such as milling equipment, farmers have decided to take the risk and attempt to revitalize New England's grain growing (Powell, 2008).

Finding 2: Despite the fact that most farmers had different ideas of what they want in a machine, there is an overall need for one that can make harvesting grains at a small-scale more efficient and cost-effective.

In our interviews, farmers and distributors had different ideas about the design of a small-scale machine capable of harvesting grains. There was a consensus, however, that a machine of that sort was needed. One of the current practices for harvesting grains on small-scale farms is to use older combines, dating from the 1940s through the 1970s. (C. Stanley, personal communication, 11/12/2011). One of the problems facing farmers is that these older machines are continuingly braking down due to decades of use. In addition, maintenance costs are rising with each harvest due to the scarcity of replacement parts. Farmers are looking for a machine that requires less maintenance and can harvest grains more efficiently. This necessitates a machine that is designed for a one to two acre plot and can harvest at that scale with minimal losses. Also, it would need to operate in variable conditions while harvesting a variety of grains.

To get a dealer's perspective of the current demand for small-scale grain equipment, our group interviewed Joel Dufour, a small tractor dealer in Kentucky. Joel's company, Earth Tools Inc., sells two brands of walk-behind tractors, BCS and Grillo, and is one of the few American dealers for these machines. Having received continuing inquiries for this machine, Joel has identified a mini-combine as the most requested product, claiming that he has received "hundreds of calls" asking for a machine which can both harvest and thresh grain (J. Dufour, personal communication, 11/10/2011).

While combine harvesters would be the ideal product for farmers, the high costs of a combine would limit the demand for this machine. These machines are very complex due to the many steps that take place within. These processes include cutting the grain stalks, separating the grain from the rest of the stalks, as well as finer sorting and storage of the grain. Because all of these processes would have to take place in a very small space, it may be difficult to manufacture and repair these machines for a reasonable price. A system which used a machine to harvest and bind grains and a separate machine to thresh the grains would be a cheaper alternative. Since the threshing process is removed from the harvesting process there would be less that needs to be built into the machine which results in a lower manufacturing and maintenance costs. Through our interviews, we found that developing an attachment for a two-wheeled tractor would be the most feasible solution. Farmers who owned a two wheel tractor would only have to purchase the necessary attachment rather than a motor driven combine harvester. Based on our interviews with our sponsor and Joel Dufour, we assumed that most commercial farmers would be willing to spend up to $8,000 dollars for a machine to harvest grains (J. Dufour, personal communications, 11/10/2011). Subtracting the cost of the base tractor, which has a minimum price of $1,587 and a maximum of $5,899, we estimated the budget for materials and labor would be about $6,500 or less for our attachment.

Base Platform	Price	
BCS 7-Series	$1587-$4649	
BCS 8-Series	$4049-$5399	
BCS 9-Series	$4499-$5999	
Grillo G85	$1699-$3200	
Grillo 131	$4799-$5899	

Table 2: Prices of Various Walk-Behind Tractors[7]

[7] Pictures obtained from http://www.earthtoolsbcs.com/

Finding 3: Small-scale grain machines are manufactured in other countries, but not available for sale in the United States.

From our patent research in the United States, our group found few recent patents have been filed for modern small-scale grain innovations in the United States. This may be due to the fact that small-scale grain growing is an emerging trend and companies currently do not see a large enough market to invest time and resources into small-scale machines. From patent database research, we learned that the only relevant US patents which met the classifications of small-scale reaper-binder were filed before 1900. As we noted above, however, there are both markets and manufacturing bases for small-scale grain equipment internationally (C. Stanley, personal communication, 11/12/2011). Using the World Intellectual Property Organization database, our group discovered that a BCS division in India had developed a reaper-binder called the BCS 622 Reaper-Binder, which uses a modified 622 BCS tractor. From this source, our group identified a key feature for this machine which was the BCS's capabilities of harvesting and binding grain simultaneously, which saves time and fuel. According to the manufacturer within an hour, these machines can harvest an acre of grain while consuming only a liter of diesel.

The researched BCS Reaper-Binder uses a modified 622 sickle-bar mower to harvest the grain, then uses fingers to guide the harvested grain into a bundle and keeps the stalks upright. Once bound, the bundle is released in the middle of the machines cutting path. While the BCS Reaper-Binder may seem like the perfect option for small-scale grain growers in the United States, according to multiple sources, the forty year old engine of this tractor does not meet the air quality regulations set by the EPA, and thus is illegal to import into the United States (D. Cox, personal communication, 12/12/2011, J. Dufour, personal communication, 11/10/2011, A. Pressman, personal communication, 10/13/2011).

Another design we studied was a tree bundling device developed by a small company called Fischell Machinery. This mechanism can bind roots, trees, and landscaping plants in one motion with an innovative binding mechanism using polypropylene or sisal twine. This provided ideas for our binding mechanism. To get a better idea of the mechanics of this binding mechanism, we contacted Jim Fischer, one of the owners of Fishcell Machinery, who provided detailed illustrations highlighting the mechanics of the tying mechanism.

4.2 Determining End Users Needs and Design Parameters

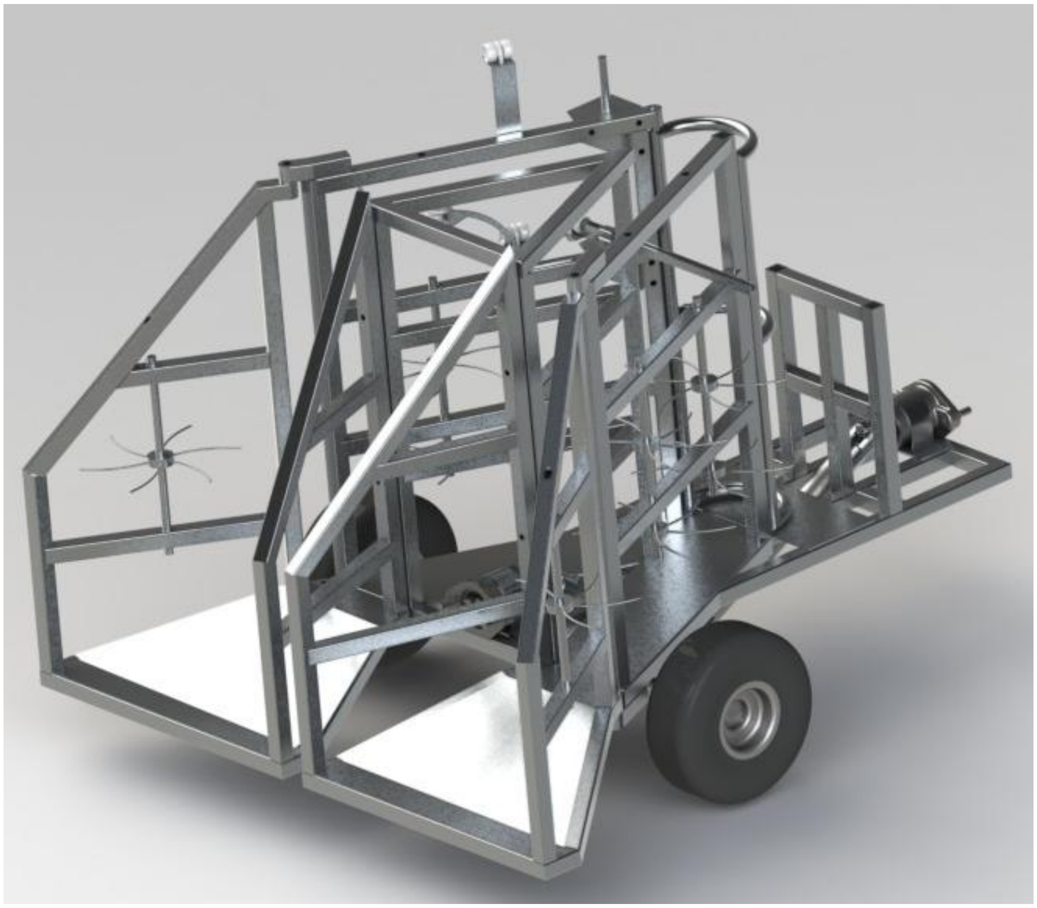

Figure 9: Initial Reaper-Binder Design

Finding 4: The end users for our reaper-binder are those who grow grains on one to two acre lots or on multiple smaller lots within urban and suburban neighborhoods.

The most important parameter for our reaper-binder was that it had to be lightweight as it is designed for growers who farm on small and/or scattered plots and need to be able to transport our machine relatively easily. Therefore, we designed our machine to be less than five feet long which is the size of a typical bed in a pickup truck. We also limited the weight of the design to not exceed a maximum of 150 lbs. This will help with the transportability of the machine. Though lightweight, the material for the machine had to be strong enough to support the weight of the grain, the tying mechanism, as well as general use and transit. Our machine also needed to be driven off of the PTO (power take-off) output of an original tractor designed by BCS America rather than its own engine. In simple term, the PTO is a drive shaft that runs off the engine of the tractor and harnesses the engine's energy for use with other attachments. Using the PTO output reduces the complexity of the machine by removing the necessity to have another engine or motor directly on the attachment. Because the farmers that will be using our product might not have a strong mechanical background, the machine itself needed to be easily repairable. The final parameter for our design was that it also needed to be tall enough to support the grain stalks throughout the binding process.

Originally, our design was focused around the sickle bar cutter attachment for a two-wheeled, walk-behind tractor manufactured by BCS America. The reason behind this was that the user may already have the sickle bar attachment like the one seen in Figure 10, so they would not have to go out and buy something they already had. In order to accommodate this, we had to have two separate channels, one on each side of the mower head, for the grain to travel into. The cutter bar is manufactured in multiple sizes, so we also had to take this into account when designing our machine.

Figure 10: BCS 45" Sickle Bar Mower[8]

At the beginning of our design process, we anticipated using two independently controlled tying mechanisms. That design was quickly altered as the final product would become too heavy and complicated. We decided that only one tying mechanism would be used

[8] Picture obtained from
http://www.groworganic.com/bcs-tiller-attachments-sickle-bar-mower-45.html

in our reaper-binder. This required a funnel shaped device to combine the two grain channels into one. At the end of the funnel, there would be a tying device and a gate that would open and release the bundles of grain once they were bound.

Power was supplied to the sickle bar attachment through the PTO output of the two-wheeled tractor. In our design, the output shaft of the PTO from the tractor (left side of Figure 11) was connected to that of the sickle bar (to the right of the wheel in Figure 11) by a universal joint. Because we need to supply power to the sickle bar, we designed the floor of the binder to be high enough to make sure that the axles that drive the PTO clear the ground with distance to spare.

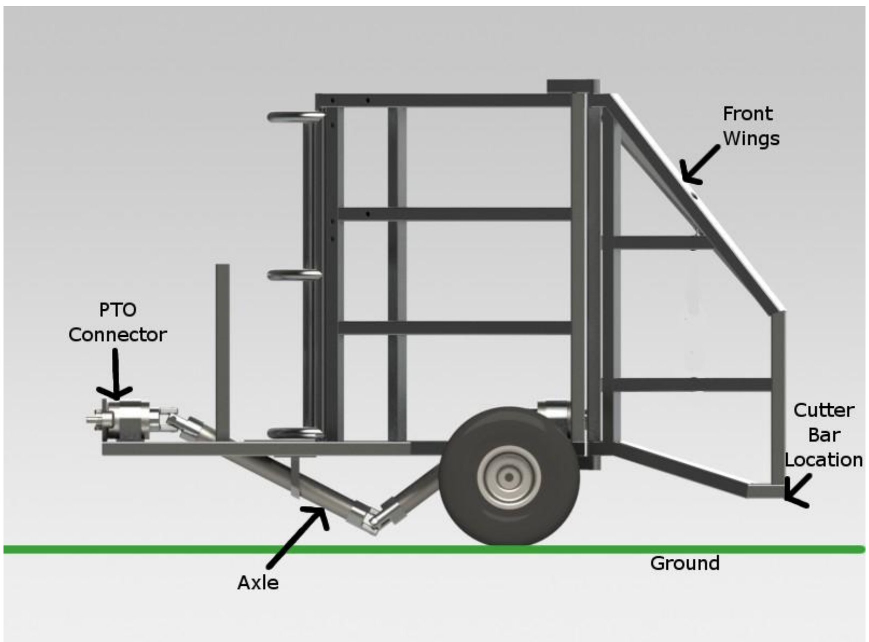

Figure 11: Drive Shaft of Initial Binder

When we adjusted the height of the floor, we determined that part of the floor would need to be at an incline to be able to have the cutter bar closer to the ground and still have clearance for the wheels and the drive shaft. In order to accomplish this, we created “wings” that attach to the main body of the binder attachment at the same height as the cutter bar. These wings are mounted with a detachable hinge mechanism, and rotate away from the each other to allow the user to attach the cutter bar attachment easily. BCS manufactures multiple length sickle bars, so we designed multiple size “wings” to accommodate for this.

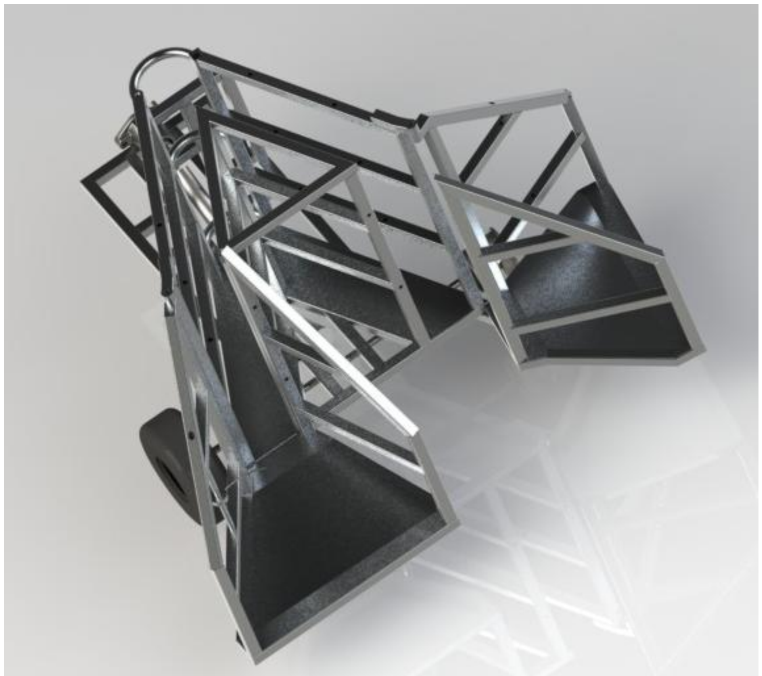

Figure 12: Replaceable Wings of Initial Binder

Once we had this main design, we realized that we needed to keep the stalks of grain upright so that they could be bound in an upright position. To accomplish this we added non-powered, free-moving fingers along the outside of the frame. These fingers were curved in the direction of flow of the grain to minimize the chances that the grain would get clamped against the side of the frame. These fingers can be seen in Figure 13 below.

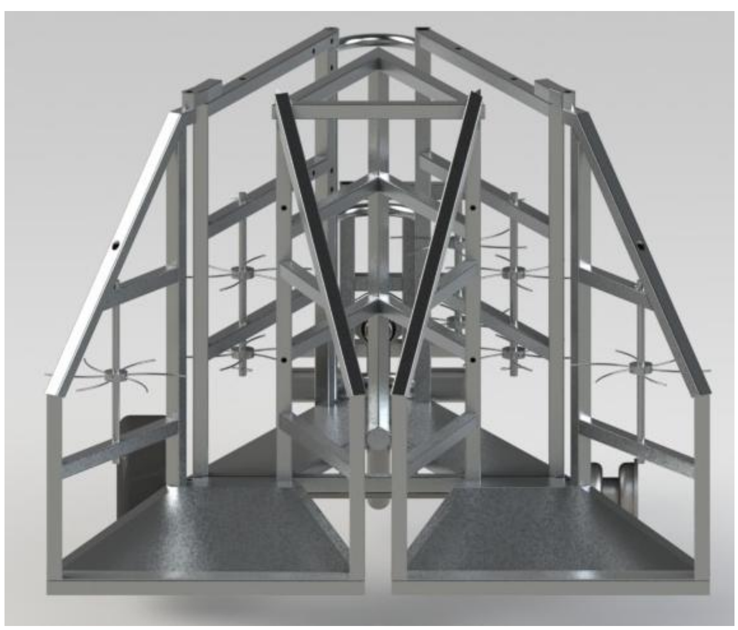

Figure 13: Feeder on Initial Binder

Finding 5: Our initial design for the reaper-binder had several key limitations that were discovered through our design review committee.

One reviewer, Dorn Cox, provided three major comments having to do with the variation in the stalks of grain. The first problem he saw was the variation in grain thickness. "There is often more volume at the bottom so the sheaves end up big at the bottom and small at the top." (D. Cox, personal communication, 2/1/2012). His solution was to make the cutting height easily adjustable, and to install more feeders vertically to better control the variation in volume. Secondly, he brought up the bundle tripping mechanism for the binder. This mechanism would detect whether or not there is a full bundle of grain ready to be harvested. If there was enough grain, it would trigger the binding operation. "Because different grains pack differently based on stiffness and variation in height of grain heads of the straw, this does not always yield a tight bundle." (D. Cox, personal communication, 2/1/2012). Dorn suggested that because varieties of grains have different structures, we need to make sure that only a tight bundle will trip the mechanism. If a loose bundle gets bound it may fall apart when handled for further processing. This leads into Dorn's third point, concerning the need for a mechanism which would pack the grain more tightly than just letting the cut stalks push the other stalks into the binding area. This would require a feeder mechanism to move the grain towards the binder.

Our second reviewer, Joel Dufour, pointed out another flaw in our initial design; the grains were unlikely to make it to the binding mechanism in the upright position we intended. He described some possible solutions to this problem, such as using belt or chain driven feeders and placing them immediately behind the grain when it is cut. This design option, however, might be prone to jamming, and it was unclear if it would fix the problem. He also brought to our attention the Italian BCS model 622 Reaper-Binder which can be seen in Figure 14 and which employs a different mechanism to reap and bind grain.

Figure 14: BCS 622 Reaper-Binder[9]

This product goes about gathering the grain towards the middle, packing both sides together. However, this product is not allowed in the United States because its motor does not meet EPA standards (J. Dufour, personal communications, 4/2/2012). The motor for this machine is specific to its design and cannot be easily substituted, as well the machine it is illegal to import. This led us to an alternative design, combining the reaping and binding techniques of the 622 Reaper-Binder utilizing the power from a two-wheeled, walk behind mower.

[9] Picture obtained from
http://www.bcs-ferrari.in/about.html

4.3 Refining our Reaper-Binder Design

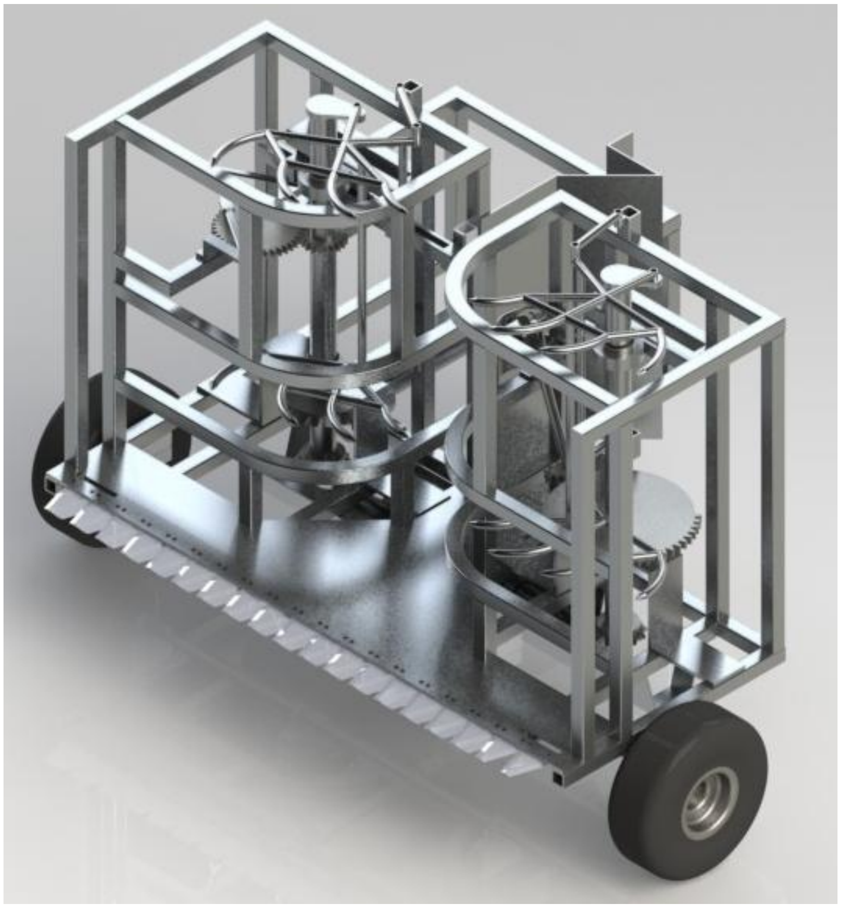

Figure 15: Final Reaper-Binder Design

Finding 6: Through the feedback from our review committee, we improved the machine by reducing the distance the cut grain travels, adding in mechanized feeders, designing our own cutting mechanism, and developing a tying mechanism.

The first step our machine takes in harvesting grains is to cut the stalks of grain by using oscillating blades at the front. Then finger like appendages, (see Figure 15 above) will transfer the stalks to the center of the machine. The stalks are then forced into in the center of the machine and travel down a channel, forming a bundle. A piece of twine, loaded across the opening of this channel, prevents the grain from falling off the back of the tractor. Once a full bundle has accumulated, an arm will move across the channel encompassing the grain with twine. The bundle size will be determined by a trigger mechanism. Once the arm moved across, an "L" shaped hook will rotate, forming a loop of twine. This hook opens a jaw as it rotates, grabbing the two ends of the twine. The loop of twine will then slide over the two free ends of twine, forming a knot. This process then repeats for the next bundle. The following explains in more detail the reasoning behind how we chose certain features for the binder.

After we received comments from our design review board, we decided to revamp our design. For this redesign, we used the BCS 622 Reaper-Binder as a base for our design in order to eliminate some of the problems that we encountered with our initial design. One of these problems was that the grain had to be diverted two separate ways because the existing sickle bar mower's body is in the middle of the attachment, see Figure 10. Thus the cut stalks of grain needed to go to the right and left of the main body. For our redesign, we decided to make our own cutter bar so that there will be no need for separate channels. In making our own cutter bar, we had the liberty to choose how and where it was driven. We choose to power the bottom bar of this cutter so that the full length of the cutter bar will be utilized without having to divert the grain around the power source. Like in our earlier design, the sickle bar will be powered from the PTO output of the tractor in order to eliminate the need to have a separate motor and power source to drive the sickle bar. This is a design feature that will reduce fuel consumption. The length of the sickle bar was chosen to be 40" based on research conducted, which was the most common length of sickle bar mower purchased. The decision to make the sickle bar with a length of 40" also met our requirement of being able to fit inside the bed of a pickup truck.

It was also decided that if the stalks of grain were dealt with sooner after they were cut; it will take less work to keep them upright. To aid in the movement of grain, two sets of fingers were added to this design which can be seen in a simplified image of our binder in Figure 16.

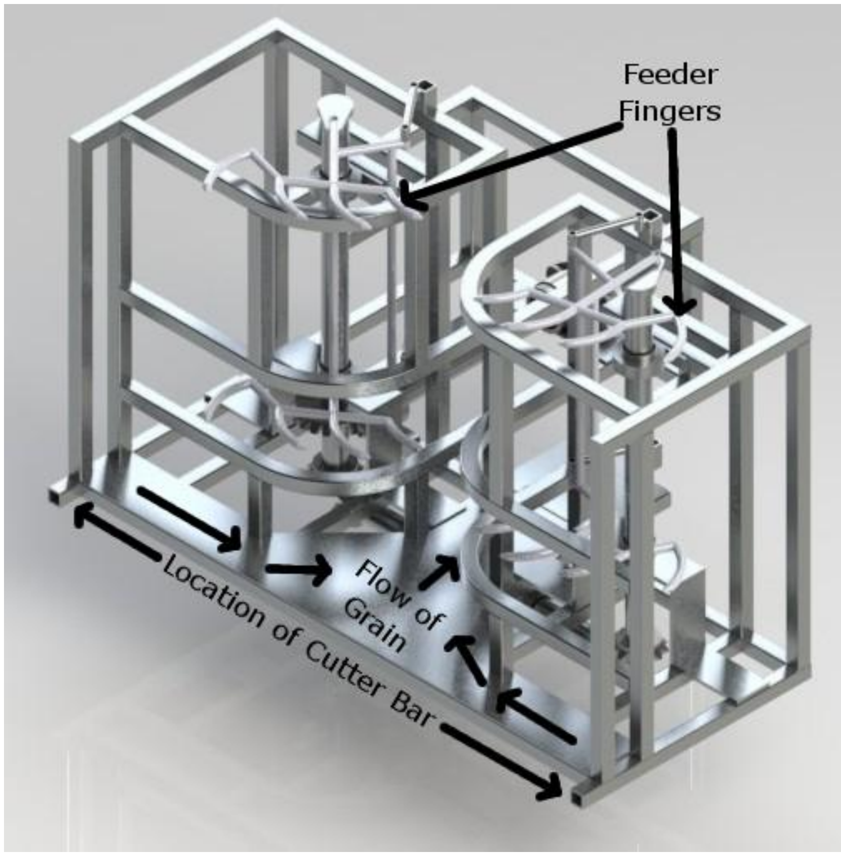

Figure 16: Framing and Fingers in Redesigned Binder

These fingers will also be powered by the PTO output and feed the stalks of grain into the middle of the binder to be bound. These feeder fingers also served the purpose of compacting the grain into the bundles as well as keeping the stalks of grain upright. This way more grain would be bound in each bundle, thus increasing efficiency. The feeders were designed so that one feeder will be at the centermost position while the other will be at the furthest position away from the center of the machine. The feeders reach the center of the binder at alternating times, maximizing the amount of grain that can be brought and compacted into the main channel. With this alternating movement, any collisions will be avoided between the two feeder arms.

The two wheeled tractor will be connected to the binder at the back left-hand side of the attachment (if viewing the machine from the front). The reason we chose this location for the placement of the tractor was so that the bound grain will fall and land to the left of the driver. If the tractor had been placed in the middle, the bundles of grain would need to be diverted to one side or the other after they were bound. This could potentially cause problems if the bundles were dropped into the uncut stalks of grain. With the design we created, the grains will fall in the center of the cutting path of the machine, thus reducing this potential problem. This process can be seen in Figure 17.

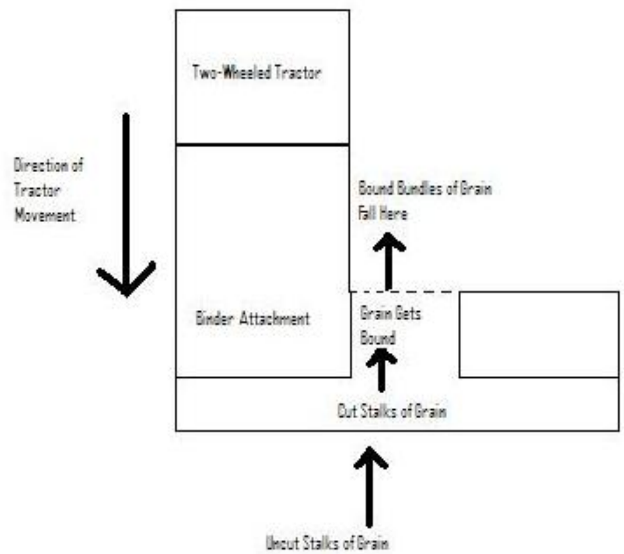

Figure 17: Simplified Version of the Binder and the Flow of Grain

The binder mechanism will be located at the end of the channel. Before any grain reaches the tying mechanism, there will be twine that is strung across the opening. The free end of the twine is held on the tying side of the machine by a rotating disk (Figure 18 D). This piece of twine will hold the stalks of grain until there is enough to be bound. The rotating twine clamp will be powered by a small motor that will be timed with the rest of the tying mechanism. The arm is located at a position to prevent grain from falling over as it is being bound. When the bundling area is filled to capacity, an arm (Figure 18 A) with twine running inside it, will move across the channel and wrap the stalks of grain with twine. This arm will be powered by a slider and bar linkage driven by gears. At the other end, a mechanism will tie and cut the twine, thus forming a complete bundle. This mechanism will be a hook (Figure 18 B) that rotates around and creates one loop of twine. At a point along the rotation, a jaw (Figure 18 C) that will be hinged on the hook, opens and then closes, grabbing the two ends of twine.

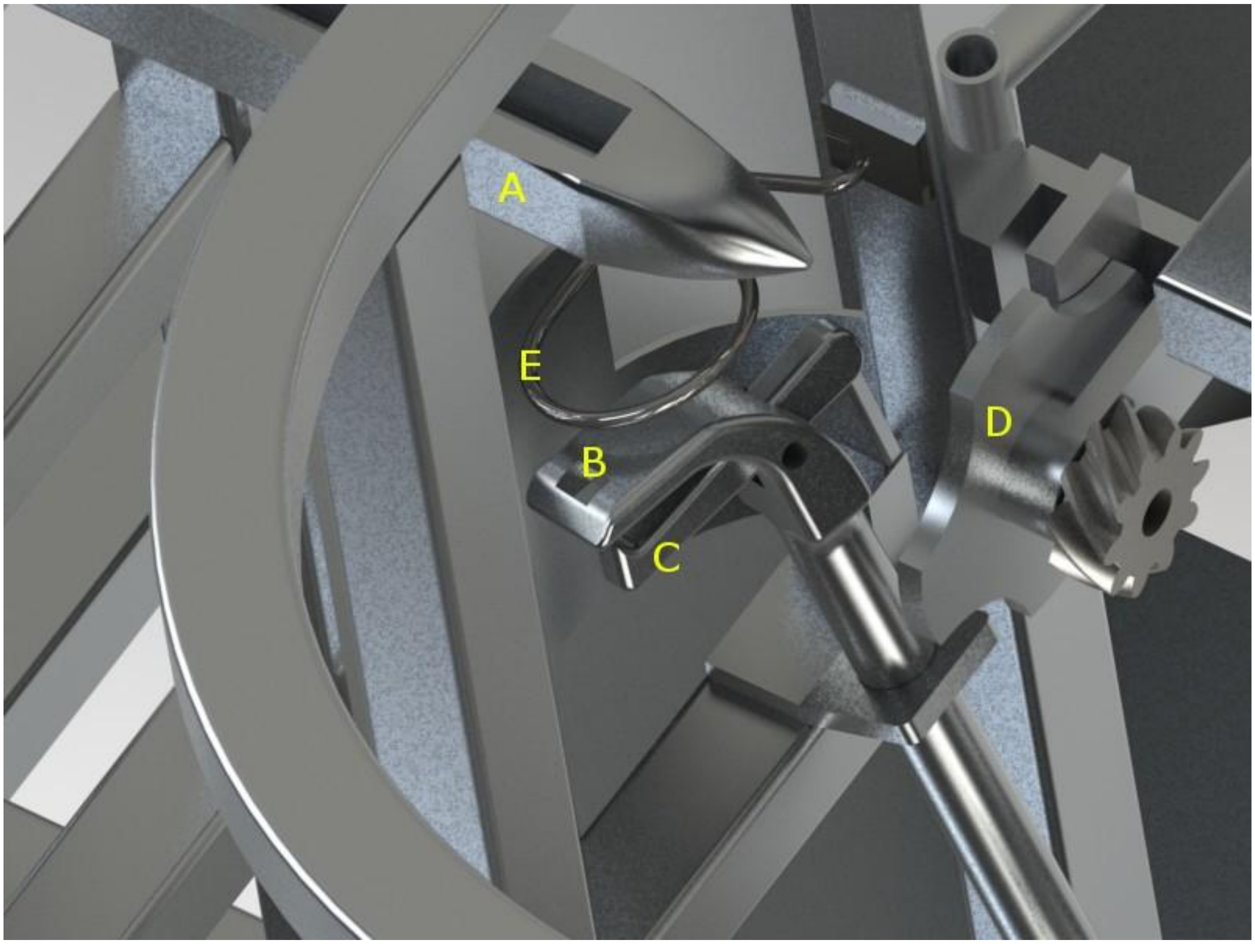

Figure 18: Tying Mechanism of Redesigned Binder

A metal loop (Figure 18 E) above the hook will help create the loop. At the same time, a blade cuts the twine that was brought by the arm and held in place by the disk and the hook rotates pushing the loop over the top of the two newly cut ends thus forming a knot. The tying arm will then retract back to the original position, drawing the twine back and the process will then start all over again. The newly bound bundle will then be pushed off the back of the attachment by newly cut grain.

Guards were placed on the undercarriage of the binder in order to protect the gears and axles. This will reduce the chances that debris will kick up and damage the gears. Another guard was places in the channel to protect the rotating hook from catching any of the stalks of grain.

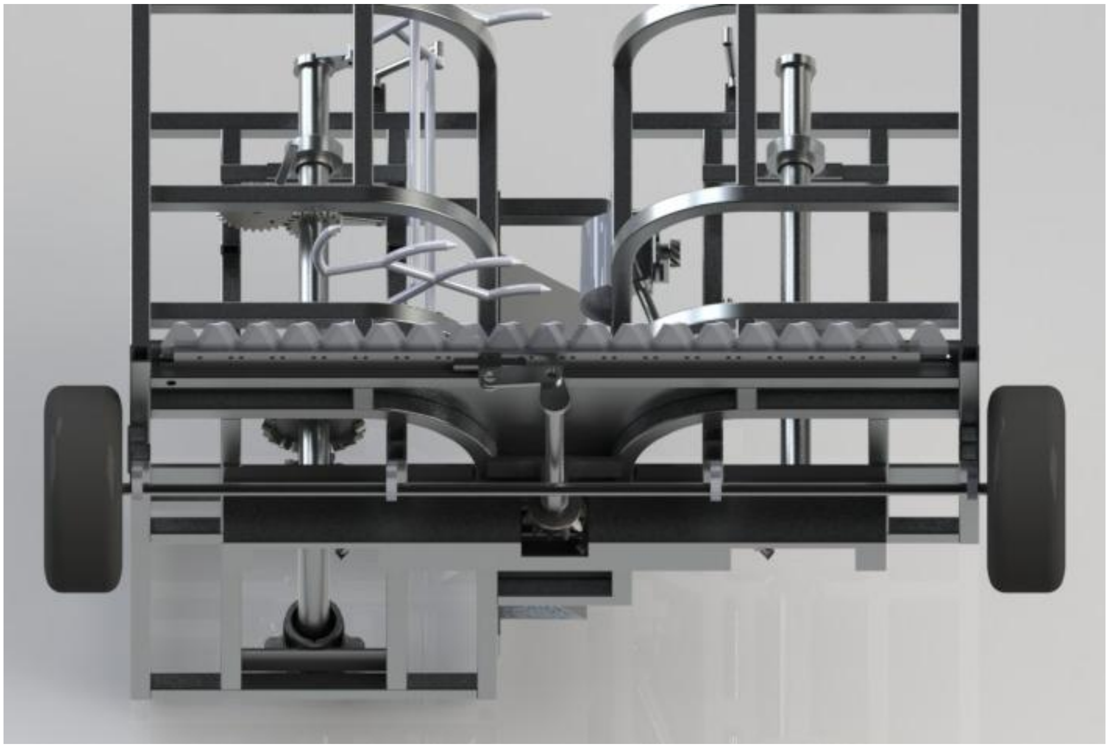

Figure 19: Bottom with Guard for Redesigned Binder

For our redesign, we did a very basic cost analysis of the materials used. This consisted of looking at the materials for the main parts of our binder: the main frame, the feeders, and the axles. A list of these items was generated and the price was determined by using current 2012 prices for the materials as it was listed on the website McMaster Carr. These tables can be viewed in Appendix B: Cost Report. The results of these calculations determined that the majority of the material would cost around $620. We estimated that the rest of the materials and labor needed for manufacturing will cost around $2,000. A full cost analysis will need to be done to a refined design in order to get a more valid cost of manufacturing.

Chapter 5: Conclusions and Areas for Future Research

From our interviews with farmers, officials with the New England Organic Farming Association, farm machinery distributors and others, we found that there is an emerging interest in the small-scale grain production and a need for a low cost machine that could efficiently harvest grains on a small-scale. From our research, we established that there are no suitable small-scale grain harvesting machines available to consumers in the United States and that it is unlikely in the near future that these manufacturers will adapt foreign models for domestic use.

Our reaper-binder is designed for an emerging market, one that is not yet at sufficient size to interest tractor manufacturers. However, there are a few different potential end users that could benefit from our reaper-binder. The first would be a current farmer who grows grains on a one to two acre plot. This could include multiple lots that would be in need of portable equipment like our grain binder. Our product could also be used by urban growers seeking to diversify their production, and exploit new markets such as local bakeries and other retail outlets. To reduce the upfront costs, urban growers could purchase the reaper-binder communally. This could introduce more local grains to communities through farmers markets and other forms of direct marketing, such as Community Supported Agriculture.

Even though our project only focuses on the grain bundling aspect of small-scale grain growing, we researched other aspects as well. The basics steps of growing grain are planting, harvesting, binding, threshing, cleaning, and milling. The machine we designed handles the harvesting and binding aspects. After harvesting grain with our binder, the threshing process can begin. Threshing is done to the bundles to remove the seeds from the chaff. On a small-scale this process is normally done by hand, which is a very inefficient, laborious process. After talking with a few of our contacts, we recommend buying or building a small machine similar to John Howe's thresher/winnower device that he has created (Northern Grain Growers, 2011). This machine efficiently separates the seeds of the grain from the chaff by sending it over a screen with force. The seeds fall through the holes in the screen.

There are aspects of our design that need further refinement given the time constraints of the project, particularly the timings for the tying mechanism and the tying arm. Currently, they are both driven off of the feeder arm axles. The problem with this is that the tying mechanism is moving constantly, regardless of the amount of grain ready for bundling. Therefore, a timing mechanism needs to be implemented based on the amount of grain required for a full bundle. Measuring the amount of grain that is required is a complex issue. With mechanism of either a switch or a sensor, the rest of the tying operation would be triggered. Another aspect for further research would be designs to cut grain at different heights. Depending on the type of grain grown, the cutting height will vary. By designing a machine that can have variable cutting heights, a farmer will be able to grow a variety of grains. There are most likely other small unknown issues that could only be found and fixed if a prototype were built and further time was spent on design and testing. This was not accomplished due to restrictions in time and lack of resources. Ideally, other designers would look at our model and determine a plan for the manufacturing of our design. After that, a prototype would be built and tested to see if there are any issues that need to be worked out. Through a series of iterations and a market study, the binder could then be sold to farmers.

References

Beatley, T. (2011). *Biophilic Cities: Integrating Nature into Urban Design and Planning*

Cambou, D. (Producer), & . (2008). *Modern marvels: Wheat.* [Video/DVD] History Channel.

Damodaran, H. (2007). Manual Wheat Harvesting Behind Lower Arrivals. *The Hindu Business Line*, (April 19) Retrieved September 9, 2011 from http://www.thehindubusinessline.com/todays-paper/tp-agri-biz-and-commodity/article1655773.ece

Darby, H. (2010). Managing Cereal Grains for Forge. http://www.uvm.edu/extension/cropsoil/wp-content/uploads/managing-cereal-grains-for-forage.pdf

Engelhaupt, E. (2008). Do Food Miles Matter? Environmental Science & Technology. *42*(10), 3482. doi:5/15/2008. http://pubs.acs.org/doi/pdf/10.1021/es087190e

Erickson, D., Lovell, S., & Mendez, V. (2011). Landowner Willingness to Embed Production Agriculture and other Land use Options in Residential Areas of Chittenden County, VT. *Landscape and Urban Planning,*

Giedrius, P., & Vida, M. (2009). Land Use Policy.*27*(2). http://dx.doi.org/10.1016/j.landusepol.2009.07.008

Greenworks Philadelphia. (2009). *The Mayor's Office of Sustainability,* http://www.phila.gov/green/greenworks/pdf/Greenworks_OnlinePDF_FINAL.pdf

Groundwater - Manual of Water Supply Practices, M21 (3rd edition) (2003). American Water Works Association (AWWA). Retrieved from http://www.knovel.com/web/portal/browse/display?_EXT_KNOVEL_DISPLAY_bookid=3571

Hess, D. (2005). Case Studies of Community Gardens and Urban Agriculture: Portland, Oregon. http://www.davidjhess.org/PortlandCG.pdf

J. W. R. Whitehand, Peter J. Larkham. (1992). Urban Landscapes: International Perspectives, 187.

Jarosz, L. (2007). The City in the Country: Growing Alternative Food Networks in Metropolitan Areas. *Journal of Rural Studies*

John Deere. (2011). Retrieved 9/25/2011, from http://www.deere.com/wps/dcom/en_US/regional_home.page

Lashgari, M., Mobli, H., Omid, M., Alimardani, R., & Mohtasebi, S. (2008). Qualitative Analysis of Wheat Grain Damage During Harvesting with John Deere Combine Harvester. *Int J Agric Biol*, *10*(2), 201-204.

Leah Koenig. (2010). The Breadbasket of America: New England?, *The Atlantic*, http://www.theatlantic.com/life/archive/2010/03/the-breadbasket-of-america-new-england/37830/

Lovell, S. (2010). Multifunctional Urban Agriculture for Sustainable Land use Planning in the United States. *Sustainability*, 2499. http://www.mdpi.com/2071-1050/2/8/2499/

Masson-Minock, M., & Stockmann, D. (2010). Creating a Legal Framework for Urban Agriculture: Lessons from Flint, Michigan. *Journal of Agriculture, Food Systems, and Community Development*, *1*(2)

Matheson, C. (2009). Shops and Recipes for Locally Grown Grains. *Yankee Magazine*, Retrieved from http://www.yankeemagazine.com/issues/2009-09/food/wheat

Mohamed, G., Bruno, L., Genevieve, N., & Patrice, R. (2006). Agricultural systems.*90*(1-3)

National gardening association. (2012). Retrieved January 16, 2012, from http://www.garden.org/

Northern grain growers association. (2011). Retrieved September 3, 2011, from http://northerngraingrowers.org/

Office of the Mayor. (2011). *Mayor Emanuel Commends City Council Approval of Ordinance Supporting Affordable Housing, Improved Access to Jobs, and Urban Farms,* Chicago, Illinois: http://www.cityofchicago.org/content/dam/city/depts/mayor/Press%20Room/Press%20Releases/2011/September/9.8.11AffordableHousing.pdf

Pimental, D. (2006). Impacts of Organic Farming on the Efficiency of Energy use in Agriculture. http://www.organicvalley.coop/fileadmin/pdf/ENERGY_SSR.pdf

Pitzer, S. (2010). Growing your Own Wheat. *Mother Earth News*, Retrieved from http://www.motherearthnews.com/Real-Food/Growing-Wheat-Types-Of-Wheat.aspx

Powell, R. (2008). Grain Expectations *on the Comeback Trail with Local Wheat Growers*. *Edible Pioneer Valley,*

Rathke, L. (2011), Local Wheat is Coming Back: Grain Growers Finding Niche. *Worcester Telegram,* Retrieved from http://www.telegram.com/article/20110828/NEWS/108289835/1002/business

SPIN Farming. (2011). Retrieved November 12, 2011, from http://spinfarming.com/

US Department of Agriculture. (2009). *2007 and 2002 US Department of Agriculture Census* doi:02/04/09

What is a CSA? farm direct. (2006). Retrieved April 21, 2012, from http://www.illinoisfarmdirect.org/Learn_More/csa.html

Wight, H. (2011). The History and Processes of Milling. *HumJournel*, Retrieved from http://www.humjournal.com/article/history-and-processes-milling#.TmEJS9Z2J_U.email

Zaal, F. (2002). World Development.*30*(7) http://dx.doi.org/10.1016/S0305-750X(02)00030-X

Appendix A: Sponsoring Organization

Our sponsor's mission is to design and develop a prototype for a small grain machine. This machine needs to fit certain requirements that will be based on interviews and research that we will conduct. This product will also need to be technically, economically, and socially feasible. Our sponsor mainly works for the National Sustainable Agriculture Information Service, which is a project that was developed, and is currently managed by NCAT, the National Center for Appropriate Technology. It was formally known as ATTRA but recent federal budget cuts left them without funding. Earlier this year, ATTRA folded and joined NCAT under the name of the NCAT: Sustainable Agriculture Project. Originally funded by the United States Department of Agriculture's Rural Business-Cooperative Service, the Project is now funded by fees that they charge for publications and private contributions from friends and supporters. NCAT is a private organization that is primarily funded by the U.S. departments, but also is funded by numerous other businesses and organizations.

NCAT currently has six regional offices around the country, with its main headquarters based in Butte, Montana. Figure 20 shows a map of the distribution of these offices across the country.

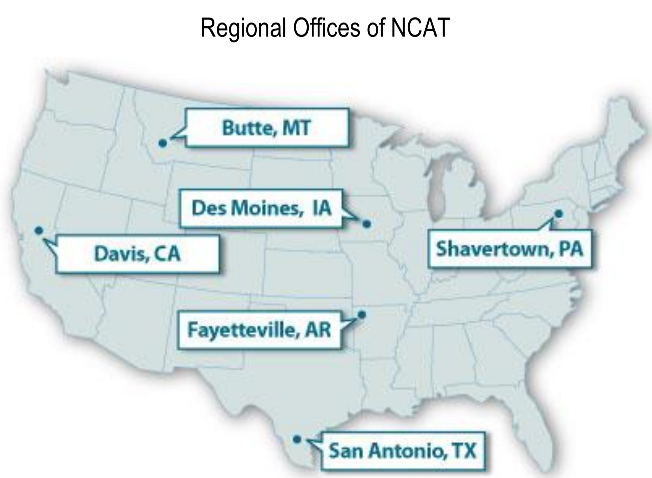

Figure 20: Regional Offices of NCAT[10]

The easiest way to gather information from the Project is from their website. There, they publish articles and other types of multimedia related to fourteen different topic areas covering such topics as: beginning farming, energy alternatives, small grain production, marketing organic

[10]Picture obtained from
http://www.ncat.org/regional_offices.php

grains, grain processing, local food systems, and grain drying. These resources provide the designer with a preliminary background on the current practices used by farmers. Right now, there are over 300 publications posted on their website. Many of these publications are free to download publicly. They also publish a weekly e-newsletter about sustainable agriculture called the Weekly Harvest, and a bimonthly newsletter that focuses on a single specific topic within sustainable farming. Currently, you can contact the Project through email or telephone, and talk with one of their program specialists. Each of the six regional offices has their own agricultural specialists that focuses in sustainable agriculture related to each individual region. Most of these program specialists have advanced degrees in a related field, and many have grown up on or currently manage a farm. The Projects website also provides a number of search-able databases that includes: Local Food Directories, Directory of Organic Seed Suppliers, Sustainable Agriculture Organizations and Publications, and Sustainable Farming Internships and Apprenticeships.

Our primary sponsor Andy Pressman, is a farmer of a two acre farm in New Hampshire, an educational advisor, and provides the Sustainable Agriculture Project with technical assistance. His experience as a farmer, educator, and researcher will be a great addition, providing hands on guidance, as well as, a vast number of resources and knowledge during the development of our grain machine. During the prototype and testing phase, Andy can assess the prototypes relevancy to real world farming in the New England area.

Other organizations that are similar to NCAT are: the USDA, the Northern Grain Growing Association, the Northeast Organic Farming Association, various projects taking place at Universities nationwide, and a variety of smaller non-profit organizations. The USDA has a program called “Know Your Farmer, Know Your Food”. Their goal is to strengthen local and regional food systems. The USDA and this program are partners with the Sustainable Agriculture Project. The USDA has developed resources such as a farmer’s market locater to find markets near you. The Northern Grain Growers Association is an organization based out of Vermont that helps and supports local farmers both new and established. They provide education, a mechanism for seed exchange, as well as network opportunities for farmers to communicate. They also help connect grain farmers to local bakers and others that are interested in local grain. As of now Northern Grain Growers Association is independent of the Project. The Northeast Organic Farming Association educates farmers about organic and sustainable farming, as well as, small-scale farming, both rural and urban, and other related topics. They also provide a variety of publications available for purchase, organize conferences around the northeast, and similarly associated programs.

Appendix B: Cost Report

Main Frame Materials

1 x 1 x 0.125 6061 Aluminum Tubing

QTY.	Length (in)	Total Length (in)
1	32.5	32.5
6	5.5	33
1	39	39
8	10.25	82
8	9.42	75.36
10	21.5	215
2	22.5	45
4	10	40
1	16	16
3	6.5	19.5
3	17.75	53.25
2	7	14
4	1.85	7.4
2	9	18
1	16	16
1	15	15
2	2.02	4.04
1	5.54	5.54
2	11	22
2	10.88	21.76
1	17.5	17.5
1	39	39
2	14	28
1	15.75	15.75
2	9.5	19
2	15	30
1	5	5
2	4.38	8.76
1	6	6
1	1.55	1.55
1	1.55	1.55

2	4	8
2	4	8
1	12	12

Total (in)	Total (ft)	Number of 6 foot lengths approx.	Price (6')	Total Price
974.46	81.205	13.53416667	27.25	368.806

Table 3: Main Frame Materials

Axle Material 6061 Aluminum

Type	Dia.	Length	Quantity	Total Length (in)	Length (ft) rounded	Price $
solid	1.5	24.25	2	48.5	4	63.88
solid	1.5	14	1	14	1	12.78
solid	1.5	20.55	1	20.55	2	
solid	0.875	10.75	1	10.75	1	15.54
solid	0.625	46	1	46	4	16.71
tube	0.5	5	4	20	2	20
					Total Price	128.91

Table 4: Axle Materials

Feeder Material 6061 Aluminum

QTY.	DESCRIPTION	LENGTH (in)	TOTAL LENGTH (in)
1	PIPE, SCH 40, .50 DIA.	2.17	2.17
2	PIPE, SCH 40, .50 DIA.	0.64	1.28
1	PIPE, SCH 40, .50 DIA.	6.44	6.44
1	PIPE, SCH 40, .50 DIA.	0.8	0.8
1	PIPE, SCH 40, .50 DIA.	3.1	3.1
2	PIPE, SCH 40, .50 DIA.	0.5	1
1	PIPE, SCH 40, .50 DIA.	3.19	3.19
3	PIPE, SCH 40, .50 DIA.	3.71	11.13
1	PIPE, SCH 40, .50 DIA.	3.25	3.25
2	PIPE, SCH 40, .50 DIA.	0.75	1.5
1	PIPE, SCH 40, .50 DIA.	4.44	4.44
2	PIPE, SCH 40, D1@@right feeder	15.25	30.5

1	PIPE, SCH 40, 6.50 DIA.	2.18	2.18	
1	PIPE, SCH 40, 6.50 DIA.	6.26	6.26	
1	PIPE, SCH 40, 6.50 DIA.	3.37	3.37	
1	PIPE, SCH 40, 6.50 DIA.	3.72	3.72	
1	PIPE, SCH 40, 6.50 DIA.	0.5	0.5	
1	PIPE, SCH 40, 6.50 DIA.	3.11	3.11	
1	PIPE, SCH 40, 6.50 DIA.	4	4	
1	PIPE, SCH 40, 6.50 DIA.	6.5	6.5	
1	PIPE, SCH 40, .50 DIA.	4.6	4.6	
1	PIPE, SCH 40, .50 DIA.	4.46	4.46	
1	PIPE, SCH 40, 6.50 DIA.	4.46	4.46	
1	PIPE, SCH 40, 6.50 DIA.	4.6	4.6	
			Total (in)	Total (ft)
			116.56	9.713333
Total (ft)	*2 feeders (ft)	Number of 6 ft lengths	Price (6 ft)	Total Price ($)
9.71333	19.42666667	3.237777778	35.17	113.8726

Table 5: Feeder Materials

Appendix C: People Contacted

Contact	Date(s) Contacted	Affiliation
Andy Pressman	9/16/2011 10/13/2011 12/14/2011	Sponsor, Farmer
Dorn Cox	10/28/2011 12/12/2011	Farmer in NH
Eugene Canales	11/21/2011	Owner of Ferrari Tractor
Joel Dufour	11/10/2011	Owner of Earth Tools
Clifford Hatch	10/25/2011	Farmer at Upingill Farm
Christian Stanley	10/3/2011 11/12/2011	Valley Malt
Julie Rawson	9/28/2011	Many Hands Organic Farm
Jack Kittredge	9/28/2011 10/7/2011	Head of NOFA
Chris Callahan	10/6/2011	Engineer, NY
Eugene L'Etoile	10/13/2011	Farmer at Four Star Farm in Northfield, MA
Steve Normanton	10/18/2011	Farmer in Litchfield, NH
John Howe	11/21/2011	Innovated Farmer
Jim Fischer	1/23/2012	Fischell Machinery LLC