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Opening Agriculture: Alternative Technological Strategies for Sustainable Farming

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Opening Agriculture: Alternative Technological Strategies for Sustainable Farming

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Abstract

This thesis investigates the potential for alternative technology development for the purposes of improving sustainable agriculture. By synthesizing ideological frameworks from Agroecology, Appropriate Technology and Open Source Hardware, a set of benchmarks are defined in order to gauge the sustainability of existing agricultural technology, as well as guide the development of new farm technology. Using these benchmarks, a number of practical farm technology projects envisioned by the author are discussed, with an emphasis on the design and construction of two specific projects, an egg incubator and an electric fence charger, both built with salvaged materials and open-source documentation. While the cost of each project was far less expensive than its commercial equivalent, time spent and labor costs are examined and discussed in light of other future open-source farm projects.
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This thesis is essentially a stuffy, academic love-letter from a technophile to his love of farming. Without strong friends and mentors in both technology and agriculture (two words which you’ll find in abundance in this document), it could never have been accomplished. My sincere thanks to Dale Miller, Alicia Gibb and Jill Harrison—your encouragement, feedback, ideas and friendship have sustained me through periods of despair and frustration with this project. None of this could have happened if not for your work in getting my brain thinking in new ways and helping me stay focused.

Thanks to the entire crew at the ATLAS BTU lab, for inspiring me with your consistent output of interesting work. Special thanks to Abhishek Narula for helping me not electrocute myself.

My deepest gratitude to André Housseny, his family, and the entire farm team at Jacob Springs Farm, where I’ve had the chance to cultivate a new knowledge and love for farming.

And to René and Royal—you are my true joy, every day.
Introduction

This thesis explores alternative approaches to agricultural technology, specifically focusing on the potential for Open Source Hardware and methodologies to advance and improve sustainable agriculture. Within the document, these terms will be more clearly defined, both using established definitions by experts in these fields, as well as through anecdotes and examples of projects going on in the world at the time of this writing. First, though, the primary questions of my work should be clearly stated: First, can Open Source Hardware make a legitimate impact on the world of agriculture? Secondly, can farmer lives be markedly improved by the widespread adoption of these techniques? And finally, what place, if any, does this approach to technological development have within the larger conversation about “sustainable agriculture”? Regarding the last question, I would emphatically suggest that these two ideologies (open-source and sustainable agriculture) have a great deal to offer and learn from one another. However, it would be logistically improbable to frame this paper within the entire philosophical gamut of “sustainable agriculture” or “open source,” both of which are often given broad (and sometimes conflicting) definitions by the myriad movements that use them. Instead, I’ve attempted to narrow the topic’s scope by investigating and synthesizing ideas from three established schools of thought: Agroecology, Open Source Hardware, and Appropriate Technology. Although the overlap between these three disciplines is sometimes small, by comparing their principles and examining the results of their practical applications, the benefits of combining these approaches into the development of open, environmentally sustainable agricultural technology will become more apparent.

This thesis is divided into two primary sections, one written and one practical. In the background section, the gains of modern agricultural technology are contrasted with some of the
environmental consequences that result from those gains. Conventional models for innovating within agriculture, namely Land Grand Universities and agribusiness firms, are contrasted with alternative methods for innovation, at which point the Agroecology, Open Source Hardware and Appropriate Technology are explored in more detail, along with five primary challenges that I believe must be overcome for new agricultural technology to harmonize with sustainable agriculture.

The second, practical section of the thesis is an exhibition and discussion of practical projects. In order to judge the feasibility of user-developed, open-source solutions for agricultural problems, I felt it would be appropriate to develop some of these solutions on my own. Using the farm on which I work and reside as my laboratory, I collaborated with others both on and off the farm to uncover agricultural challenges that might be solved using salvaged materials, Arduino microcontrollers, and affordable sensors. A number of the proposed projects are outlined, and details are provided regarding the two projects that were selected for completion: a large incubator for incubating chicken and duck eggs and an inexpensive, reliable electric fence charger. Through the design and construction of these projects, considerable lessons were learned about the utility and feasibility of the open-source farming strategy explored within this thesis. In addition to chronicling the construction of these two projects, I also spent time developing a web-based information database through which interested parties can learn how these projects were completed, get instructions for replicating them, and leave their own feedback and suggestions for future farm projects.

When considered together, I hope that the two sections of the thesis will serve as a starting point for future study and discussion regarding the changing landscape of agricultural technology. While no singular solution will solve the challenges of agriculture in the 21st century,
reframing our views on technology and discussing the *who* *what* *when* *where* and *whys* of its use are a critical piece of the puzzle.
Section 1: Background
The State of the Farm

Farming and technology have a long, complicated relationship. Agriculture is itself a technological development, an innovative response to population growth by our hunter-gatherer ancestors. In the twentieth century, society has heavily relied upon technology to meet the same challenge: how to feed an ever-increasing global population. Malthusian predictions of large-scale famine and disease due to a population explosion have been largely muted by the advent of new agricultural technologies throughout the twentieth century, collectively called the “Green Revolution,” which brought about unprecedented growth in the world’s agricultural output. New plant breeds, advances in chemical fertilizers and pesticides, and new solutions for large scale crop production and processing have ushered in an era of vast agricultural productivity. Furthermore, a new “Green Revolution”, being developed in laboratories and fields across the globe, has the potential to increase crop yields, promote drought and disease tolerance, and even enhance the nutritional profile of crops, all through the modification of genetic sequences within the plants and animals cultivated by farmers around the globe. With all this apparent progress, what purpose does it serve to investigate alternative pathways to technological development within agriculture?

Despite the gains of the past century, there are substantial reasons to examine alternatives to the current agricultural system. First, many of the yield gains made within the past century have come with considerable environmental consequences. While industrial advances have made nitrogen and phosphorus fertilizers more widely available to farmers, the increased use of these fertilizers are frequently linked to groundwater contamination and waterway eutrophication. Agricultural fertilizers are the leading cause of non-point water pollution (USGS, 2008), and
nutrient accumulation resulting from fertilizer runoff has been linked to hypoxic dead zones along numerous coastal areas worldwide (Beman, Arrigo & Matsen, 2005).

The rise of innovative agricultural technologies for food production and distribution has also greatly expanded the agriculture’s energy footprint. The Food and Agriculture Organization of the United Nations (FAO) estimates that global crop and livestock production through cultivation, harvesting, water pumping, animal housing, storage, drying and other on farm processes, consumes nearly 6 exajoules of energy per year and produces almost 6 gigatons of CO₂ and equivalent gases¹, roughly 16% of all human carbon dioxide emissions. These figures are separate from the processing and transport of that food, which emits an additional 2 gigatons of greenhouse gases and consumes 42 exajoules of energy per year, approximately 14% of total global energy consumption (FAO, 2011, pp. 9-12).

Technological advances in mechanization, especially within planting and harvesting, have increased productivity and reduced labor requirements, but many of these advances also rely on the institution of large-scale monocropping to maximize efficiency. Growing extensive plots of a single crop amplifies the risk and prevalence of pests and diseases within that crop (Warner, 2007), a problem which is typically remedied through the application of chemical pesticides. Many of these pesticides have adverse ecological effects on wildlife (Tagmeier & Duffy, 2004; Gibbons, Morrisey, & Mineau, 2015; ), and airborne drift from pesticide applications often makes its way into nearby communities, wreaking havoc on the health of residents (Harrison, 2011).

The environmental consequences of industrial agriculture cast doubt on the sustainability of current agricultural production, and despite current estimates that global food production is keeping pace with population (discounting the distribution issues that lead to hunger among

¹ “Equivalent gases” refers to methane (CH₄) and nitrous oxide (N₂O) in amounts equivalent to the atmospheric warming potential of carbon dioxide.
many communities worldwide), the projected 9.6 billion residents of Earth in 2050 will require production increases of approximately 69% from 2006 levels (WRI, 2013). However, with much of the planet’s arable land already under production and potentially catastrophic climate change looming on the horizon, farmers need sustainable solutions now more than ever. Institutions are increasingly looking to biotechnology and genetically modified organisms as a solution, and while there appears to be potential for many of these products to address some of the problems listed above, most of the voices within the sustainable agriculture movement are, at best, skeptically cautious about these solutions. Perhaps equally troubling (and more relevant to the topic at hand), the increasing development of proprietary farm technologies by private firms, coupled with the rise of patents awarded for genetically modified organisms, has led to a number of unprecedented legal challenges for farmers utilizing these new products. Evidence presented by Kloppenburg (2004) and Pechlaner (2010) strongly suggests that agribusiness firms exploit the legal frameworks of the patent system as a capital accumulation strategy, in many cases pressuring farmers to sign contracts for the use patented seeds, restricting seed saving by farmers, and initiating lawsuits against farmers suspected of violating intellectual property laws. Considering the growing financial power of many of these agribusiness corporations (Gunderson et al., 2014) and the steady decline of farmer incomes (El-Osta et al. 2007), it is not difficult to see the growing power disparity between the parties in these disputes. This shift of power away from farmers and public institutions and towards private agribusiness firms is part of a larger trend in agriculture, and understanding this will be critical in examining the value of alternative forms of technological innovation. The focal shift within the U.S. Land Grant University (LGU) system over the past several decades provides a useful framework for examining this shift in the context of agricultural innovation.
Pools of Knowledge

The 1862 passage of the The Morrill Act laid the legal framework for the creation of the nation’s land grant university system, awarding 30,000 acres of federal land to each state in order to “teach such branches of learning as are related to agriculture and the mechanic arts, in such manner as the legislatures of the States may respectively prescribe, in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life” (7 U.S.C. § 304). The creation of these institutions throughout the country reflected the public sentiment surrounding agriculture and higher education as a public good and was a significant step in increasing the availability of higher education (Warner, 2007). The Hatch Act in 1887 and the Smith-Lever Act in 1914 expanded upon this system by authorizing federal funding of agricultural experiment stations which acted as local extensions of each state’s land grant institution. These stations provided their local farmers with practical agricultural advice and conducted experiments around plant breeding, soil improvement and mechanization, in essence pioneering the foundation for modern agricultural science in the United States.

However, as the twentieth century progressed, these institutions began to transform in their methods and audience, especially as private agricultural input providers began to increase pressure to promote their own solutions to farmer need (Buttel, 2005). Academic critics attribute this to the Land Grand Universities following a “productionist mindset”, seeing increases in agricultural production as universally desirable and beneficial to society (Warner, 2007). Although this influence was minimized during what Frederick Buttel (2001) calls the “Golden Age” of the Land Grant institution between 1940-1970 (figure 1.1), by the 1970s onward, LGUs faced increasing criticism due to the perception that their research disproportionately benefitted larger farmers and promoted the agenda of agribusiness over the needs of rural communities.
Criticism, both from academics within and farmers outside the LGU system, correlated with a decline in state public funding and a rise in federal and private funding into these institutions. With this shift came an increased emphasis on applied techniques and a decline in locally applicable research, along with a “new model” of LGU research, in which the innovation and technology developed within Land Grant Universities is no longer transferred to farmers directly via extension offices, but is instead patented, packaged and sold to farmers via the private sector.

Figure 1.1. LGU research flow, 1940s-1970s. (Buttel, 2001).

Figure 1.2. Buttel’s “new model” of Land Grant Research. (Buttel, 2001).
(figure 1.2). This system favors farms using the agricultural techniques promoted by agribusiness firms, thus alienating farms which desire to utilize alternative farming techniques. Rather than incentivizing innovation merely for the sake of the public good, this type of productionist knowledge cultivation incentivizes the development of products that maximize revenue for their patent holders. While innovations in crop science or livestock production can still be achieved through this model, the end result is a degradation in the ability of farmers to effectively communicate their technology needs to the publicly funded institutions that supposedly exist to serve them (Warner, 2007).

In some instances, farmers unable to find alternative knowledge sources have developed organizations within their own communities to cultivate it. Groups like the Practical Farmers of Iowa and the Wisconsin Rural Development Center sprang from these types of information voids, and as they grew and developed partnerships with local Land Grant Universities, sustainable agriculture programs within those universities slowly started to emerge, albeit as comparatively small programs (Bell, 2004; Warner, 2007). Still, perhaps in response to the association of new farm technology with conventional agribusiness, there are some within the sustainable agriculture movement who promote a sort of “neo-luddism” as an alternative to the techno-heavy solutions of modern agriculture. Although a return to a primitive living might seem like a valid response when faced with the environmental damage caused by modern agriculture, doing so requires willful ignorance of the potential for technology to help solve many of the problems it helped create. For the technological optimist, the challenge is instead to reframe agricultural technology in a way that allows it to overcome its current challenges.
Through the exploration of three disciplinary frameworks and combination of key elements from each one, a critical benchmark for judging the success of new farm technology can be developed. These disciplines—Agroecology, Appropriate Technology, and Open Source Hardware—each have specific characteristics that can help in developing new ways of understanding and creating agricultural technology.

**Agroecology**

Although the environmental consequences of conventional agriculture are often acknowledged as opportunities for improvement by the parties involved, voices outside of the mainstream often posit that the negative consequences attached to agriculture require a complete change of philosophical mindset before lasting change can be made. This is the charge largely leveled by those within the Agroecology movement, a broad discipline of scholarship which seeks to apply a holistic, ecosystems approach to agricultural practice. Agroecology scholars like Norgaard and Sikor (1995) posit that conventional agriculture has its philosophical roots in modern, reductionist scientific premises, in which systems and problems can be solved merely by reducing them to their component parts, and by mastering the universal principles that underlie seemingly complex phenomena. They argue that by failing to see agriculture as a complex web of interconnected, sometimes chaotic, and subjective systems (that we are inexorably linked to by our dependence on them), modern agricultural practice moves forward without the necessary caution that should precede disruptive activity into an ecosystem, and as a result inflicts far-reaching negative environmental consequences like those detailed previously.

Agroecology, by comparison, judges the success of an agroecosystem by measuring a diverse set of interrelated parameters. Characteristics of soil composition, water use and quality, above and below ground biotic factors and overall ecosystem productivity, rather than the output of a
single crop, are taken into account (Altieri, 1995). These factors are assessed alongside the economic climate of the agroecosystem. In the same way that generating profit without consideration for the environment is unsustainable, the inverse is also true—farmers practicing ecologically sound techniques need to be able to turn a profit in order to be considered sustainable. Furthermore, agroecology also emphasizes the importance of the sociocultural factors that underlie agriculture. Personal autonomy, social justice, and equitability of returns are all considered critical to sustaining an agroecosystem in the long term, as social disparity and unrest can eventually lead to major system disruption (Gliessman, 1998).

With this holistic outlook on agriculture, Agroecology fits some (or all) of the characteristics identified as necessary to reframing the development of technology within farming. However, although technology is an important factor within agroecology, it is not its primary focus, and further perspectives should be incorporated to enrich a renewed technological outlook.

*Appropriate Technology*

In 1973, Dr. Ernest Schumacher published *Small Is Beautiful*, detailing the reasons for reevaluating the design and implementation of technology, particularly in the context of the developing world. Initially called “intermediate technology” as a means for delineating technology that is exponentially more efficient than so-called “indigenous technology” but considerably less expensive than conventional “modern” technology (Schumacher, 1973, p. 169), the design and implementation principles espoused by Schumacher were seen to extend beyond mere developing contexts, and the name of the movement was changed to Appropriate Technology to reflect the development of technological tools that were localized and appropriate to their context (McRobie, 1981).
Appropriate Technology is characterized by being “small-scale, energy efficient, environmentally sound, labor-intensive, and locally controlled” (Hazeltine, 1998, p. 4). Schumacher speaks to its relevance in agriculture specifically as the “perfection of production methods which are biologically sound, build up soil fertility, and produce health, beauty and permanence” (p.19). When attempting to reframe the role of technology in agriculture, incorporating these ideas can theoretically guide the development of technology that both considers the environment and the people using it. However, without stated practical guidelines for how to develop and disseminate information about this technology, innovations could end up being limited only to their local contexts. In the digital age, the potential for sharing developments between communities around the globe is too great to allow this limitation. Fortunately, Open Source Hardware can help provide this direction.

*Open Source Hardware*

Since the rise the formalized Open Source movement in the 1980s, arguments for the free transfer of source information to technology users have gained momentum in a number of fields, particularly in software development. Open Source development has been shown to accelerate innovation and empower users to generate new innovations on existing products (Ball, 2003; Weber, 2004) vastly expanding the number of individuals collaborating on a project by freely distributing its source material and allowing for unhindered modification and manipulation, something that is not commonly seen within traditional tech development contexts. As these benefits have become more evident, this movement has expanded beyond software into the realm of tangible objects. The principles of Open Source Hardware have only been clearly defined within the past decade, but are firmly rooted in Open Source Definition, as stated by the Open Source Initiative on its website, opensource.org. The Open Source Hardware Association
(OSHWA) defines Open Source Hardware as “a term for tangible artifacts — machines, devices, or other physical things — whose design has been released to the public in such a way that anyone can make, modify, distribute, and use those things” (OSHWA, 2015). A set of governing principles further defining this type of hardware, rules for its distribution, licensing and use are detailed on the OSHWA website, but they hinge upon ensuring that the distribution and use of the source design in question cannot be limited or withheld in any way. While it is often argued that freely distributing the source material for a piece of hardware degrades its economic and commercial viability, the rise of the Internet for information sharing and the decreased cost of materials (particularly electronic components) has led to an increase in the growth of Open Source Hardware projects, and recent case studies point to significant, quantifiable financial benefits that can be derived from Open Source Hardware projects (Pearce, 2015). The continuing success of Open Source Hardware platforms like the Arduino microcontroller (and its associated derivatives) evidences a growing community of participants who utilize and modify this type of technology (Gibb, 2014).

By allowing unfettered source access and unlimited modification of a particular technology, Open Source Hardware theoretically gives greater freedom and control to technology users. In an agricultural context, this could mean communities of farmers developing specialized, locally relevant technology based on open designs developed by the larger worldwide community. A farmer who desires to pursue sustainable alternatives to conventional agriculture but feels underserved by their local extension office or agricultural technology supplier could connect to a larger community of like-minded farmers globally via the worldwide web; if that community shared plans and solutions using clearly defined, open-source frameworks, that marginalized farmer would be connected not only socially to a greater community, but be enabled practically to
utilize and contribute to the knowledge of that community. Although this concept is not unique to agriculture, the decentralized nature of agricultural production presumably makes open source particularly appropriate to farming, releasing farmers from being beholden to the relatively narrow field of conventional technological development institutions currently available and instead allowing farmers to become active contributors in the development of tools and techniques that directly impact them.

Applying the open-source mindset to agricultural technology is not without its challenges, however. Consider a real world example:

It is a balmy November day in Ft. Meyers, Florida, and a small group of farmers, agronomists, and development activists have gathered around a large patch of sandy earth to watch an equipment demonstration. One man stands in the center of the group, tinkerering with the star of the day’s show—a prototype “no-till seed drill” that he has engineered for use by small-scale farmers. Standing just a few feet high and about 4 feet long, this machine is much smaller than a conventional tractor mounted seed drill, and has been designed, according to its inventor, to improve yields and reduce tillage requirements for farmers that traditionally rely on hand-seeding to sow crops. Presumably satisfied with his adjustments, the inventor starts the engine on the two-wheeled “walk-behind” tractor that the implement is attached to and starts the demonstration.

The crowd members are also taking part in a larger gathering—the 21st annual ECHO International Agriculture conference, and this demonstration is just one of many that will be delivered on the ECHO campus over the following 3 days. ECHO is a Florida-based nonprofit that “exists to reduce hunger and improve the lives of small-scale farmers worldwide.” Practically, this means providing agricultural technology and training in numerous countries around the world (ECHO claims to be working in over 165 different nations). Many of the techniques and
technologies deployed are developed at ECHO’s campus in Ft. Meyers, which serves as a vast plant species repository and agricultural laboratory for developing Appropriate Technology (ECHO, 2015).

After the demonstration is run, the crowd is generally impressed by the construction and engineering of the machine. The designer, who worked as an engineer for agricultural equipment manufacturer Massey-Ferguson for many years before moving into his current post as an adjunct professor of agriculture at the University of Kentucky, proudly describes his design process and tells of how he was able to leverage his standing relationships with manufacturers to provide this machine “at cost” to farmers. However, when that cost (not including the walk-behind tractor that pulls it) was revealed to be approximately 1200 dollars, some concerns began to arise. My colleague André Houssney, a farmer attending the event who has worked extensively with agriculture in Zambia, recounted it as such:

“So I mentioned to [the inventor] that the average maize farmer in Zambia only makes about 75 dollars a year, meaning this machine would take something like 18 years for a farmer there to pay off, not to mention the need for the tractor and the fuel to run it, associated repair costs, et cetera. So he tells me about how he’s worked with the manufacturer to keep costs low, because they want to help these small-scale farmers. And I say, if he wants to help, why not make the designs available publicly, so farmers might be able to assemble something similar themselves with local materials, or maybe he could sell some of the important parts in a kit to be finished and assembled by the farmer. And he just looks at me plainly and says, ‘that’s just not the way we’re choosing to go with this.’ Meanwhile, all of these sustainable development people are there just talking about how many of these things they can afford to buy and give away to African farmers. Later, he expounded on his response by...
noting that he was concerned about manufacturing quality and keeping control of the design” (A. Housseny, personal communication, December, 2014).

This story presents two distinct perspectives on agricultural technology. Although both sides see the potential benefit of the seed drill, the inventor wants to protect the integrity of his device by controlling the design and manufacturing process. It is unknown whether his motivation is merely rooted in a desire to ensure a quality product, or if he is also interested in using patented technology to accumulate profit; regardless, it contrasts with Housseny’s suggestion of opening the design so farmers could potentially manufacture some or all of the device based on their local needs and material availability. Conflicting ideas about the nature of intellectual property ownership and end-user freedom represent a challenge for those looking to define the value of Open Source Hardware in any context, but particularly in agriculture, which has seen explosive growth in both patent applications and intellectual property litigation in the past two decades (Lippoldt, 2015). Substantial political lobbying on the part of agribusiness for the strengthening of existing intellectual property laws (Graff & Zilbermann, 2007) indicates considerable potential resistance from established interests within agricultural technology. Still, for those looking to improve farmer freedom around agricultural technology and draw from the potential benefits of free, community-based development, open source has immense potential.

**Putting it into Practice**

Although the majority of agricultural technology development still conforms to mainstream methods, there are some organizations embracing some of the alternative methods discussed above. Open Source Ecology, founded in 2003 by Marcin Jacobowski, is attempting to develop what they call the “Global Village Construction Set,” an open-source set of plans for construction of “the 50 different Industrial Machines that it takes to build a small, sustainable
civilization with modern comforts” (Open Source Ecology, 2015). Many of these machines are designed for agricultural purposes, and the idea for the kit itself began with the successful design and construction of a tractor, built from scratch, on the organization’s farm in northern Missouri (Eakin, 2013). The organization has been lauded for its ambitious goals to “create the open source economy,” being listed as one of Time magazine’s “Best Inventions of 2012”.

Still, the movement on the whole is small, and while the projects pursued by Open Source Ecology are intriguing, they often extend beyond the scope of mere agriculture. To apply the lessons learned from Agroecology, Appropriate Technology, and Open Source Hardware specifically to sustainable agriculture, practical experiments had to be conducted. To judge their success, five criteria were derived from the background disciplines (figure 1.3) to serve as benchmarks for developing sustainable agricultural technology:

• The technology is designed should be responsive the specific needs of each individual situation, rather than trying to be a broad solution for all users (Localized/Specific)

• The technology should be inexpensive, rather than increasing farmer debt burden (Affordable)

• The design of the technology should make every effort to consider the broader environmental, social and economic consequences of the technology prior to implementation (Holistic)

• The technology should empower farmers to make choices about how (or even if) the technology should be used, and be accompanied with robust information to assist in making those decisions (Democratic)

Although my specific practical thesis projects are small hardware projects, I believe that the “rules” listed above are relevant to other fields of agricultural technology, such as soil nutrition, pest management and biotechnology.
• The technology should address practical problems that are agreed upon by farmers and technology providers (Useful/Practical).

![Five criteria for judging sustainable agricultural technology.](image)

**Figure 1.3.** Five criteria for judging sustainable agricultural technology.

Using these “rules,” practical projects can be evaluated for their viability as sustainable agricultural solutions. Discussion of two such projects make up the bulk of the practical section of this thesis.
Section 2: Practical Projects

Project Background

The goal of the practical section was to develop and create agricultural technology projects that ideally fit within the benchmark criteria laid out in section 1: that projects be Localized, Affordable, Holistic, Democratic and Practical. The first criteria, localization/context specificity, requires knowledge of the location where the technology will be implemented. In this instance, that location is Jacob Springs Farm, in Boulder, CO.

Jacob Springs Farm is located on a 6 acre plot just east of the city of Boulder. It specializes in “beyond-organic,” pasture-raised animal proteins, which are primarily sold to customers via its Community Supported Agriculture (CSA) program. In addition to the footprint of the farm’s main hub, other parcels of land are leased around the county to graze its livestock, which includes dairy and beef cattle, hogs, sheep, chickens and turkeys. Due to the small land area of the farm, production is intensive but relatively small; fowl are generally kept in flocks between 50 and 200 birds, the dairy herd only has four cows, and the number of hogs under the farm’s care rarely exceeds 40. Although Andre Housseny, the farm owner, has a goal to expand the size of the operation, animal welfare and environmental sustainability are high-priorities for the farm, rooted in both Housseny’s personal ethics as well as high local customer demand for meat that fulfills these values.

However, emphasis on these values, as well as the small size and limited budget of the farm, means that Jacob Springs Farm is largely resistant to conventional agricultural technology and mechanization. As a result, a considerable amount of manual labor is involved in day to day farm operations. Reducing the labor burden on the farm by developing affordable technology that aligns with the farms values was the primary goal of the prospective projects discussed when planning for this thesis began. A few weeks later, Dr. Mike Soltys of the University of Colorado
approached the farm about tasking his Engineering Design class with solving farm problems, and a number of the initial ideas developed during the thesis planning phases were presented to his class. Those projects were completed and delivered to the farm in December 2014, and although their development was largely independent from this thesis, almost all of the students elected to place their designs into the open-source realm, allowing for further modification and improvement on those designs. Many of those student projects (particularly those which did not work well) were also dismantled, and their parts were utilized to construct other projects around the farm, including the Henmulator incubator, one of the primary projects for this thesis.

The two primary projects, the incubator and electric fence charger, are found below, along with a description of the Open Agriculture Wiki. The complete list of the originally theorized projects, along with relevant sketches and design notes, can be found in Appendix A.

*The “Henmulator” Egg Incubator*

One of the primary income sources for Jacob Springs is its poultry program, which produces both eggs and meat birds. Aside from feed, the primary input cost for this program is the cost of purchasing the chicks themselves. Using combined data from five different commercial hatcheries, it was found that 2014 prices averaged between 2 and 3 dollars per chick, depending on sex, breed, and number of birds ordered. Considering the potential cost savings of hatching eggs on the farm, the construction of a large egg incubator emerged as a strong choice for an experimental project.

To achieve high hatch rates, an incubator should be able to automatically rotate the eggs, control the temperature of the hatching environment, and maintain a constant relative humidity. Most larger commercial incubators rotate the eggs by securing them in large trays that are then tilted up and down in a see-saw like motion. Temperature and humidity are monitored by a
sensor and modified using a heater and humidifier. After examining numerous commercial incubation units, we estimated that a comparable cabinet-style incubator could be inexpensively built inside a non-functioning upright freezer that was already at the farm. After removing the existing shelves from the unit, the freezer door was dismantled and the design phase began.

Initial project time was spent modeling and sketching the shelf layout, wiring, air movement systems and control circuits (figure 2.1). Incandescent light bulbs were chosen as the heat source, which were then wired in parallel within a recycled light fixture and mounted inside the base of the unit. To control the heat and humidity, an open-source, reprogrammable Arduino microcontroller recorded information from a temperature and humidity sensor embedded in the wall of the freezer housing. This microcontroller is used to manipulate two relay circuits (figure 2.2) that are wired to the lights and a small humidifier. Open-source code to control these circuits was readily available, due largely to the ubiquity of the Arduino for do-it-yourself electronics projects. A separate fan circuit, built using two discarded fans from a microwave and an old light switch, circulates air through the incubation chamber. A tray rotation motor (from the same microwave)
is used, along with custom-cut acrylic gears, to control the pivoting rotation of each egg tray. If desired, a computer can be plugged into the humidifier via a USB cable to check the current temperature and humidity, as well as make adjustments to the programmed thresholds. Future plans include the addition of a small screen to display this data in real-time.

**Results**

As of this writing, the eggs within the incubator have only completed a small portion of their 21 day incubation period within the incubator, and as such, the actual utility of the unit can only be judged by what it appears to successfully do, which is clear: the trays rotate the eggs successfully, the temperature and humidity are regulated according the programmed thresholds, and the freezer housing appears to insulate the eggs with minimal energy lost. If the incubator functions in successfully incubating and hatching eggs, it will represent a remarkably cost-efficient

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Table 2.1. Purchased components for the Henmulator. Prices based on Sparkfun.com retail prices, February 2015.
alternative to a commercial manufactured unit. While commercial incubator models with similar features and capacity range in price between 700 and 2000 dollars, the total cost of purchased materials for this incubator totaled just over 95 dollars. The low cost is due largely to the extensive use of salvaged and recycled materials, including the freezer housing, light fixture, wiring and construction materials. However, even if most of these materials had been purchased from a retail source (excluding the freezer), it would only add approximately 40-50 dollars to the total budget, still keeping the project at a financial footprint of roughly 10% the cost of a commercial equivalent.

Design and construction of the Henmulator was a considerable time investment, however. In total, the project was completed over nearly three months, and the time in design, fabrication and testing ran upwards of 25 hours. This amount of time spent would be typically impractical for a busy farmer, but one of the fundamental theoretical benefits of open-source development is that this kind of project might someday be developed not by an individual, but by interested parties all around the world. Additionally, once a working design is available on the web, the design and testing phase are largely complete, greatly reducing the time investment required to construct a finished product.
With the plans, assembly instructions and code already available, assembly of a similar unit could be finished in six to eight hours.

*The Electric Fence Charger Experiment*

Animals on Jacob Springs Farm spend a majority of their lives on pastures, rotationally grazing between various paddocks on and around the farm property. Portable electric fences are used to contain animals, and as these fences are regularly moved and exposed to the elements, they are prone to breakage and failure—particularly the device that generates the electrical impulse in the fence, known as a fence charger, or energizer. Having spent several hundred dollars repairing and replacing energizers over the past year, Housseny expressed interest in an inexpensive, do-it-yourself fence charger that could replace the powerful commercial chargers on the farm, which cost between one and three hundred dollars, depending on their power and the length of fencing that they charge.

The project began with a failed attempt to manually repair a fence charger that had been damaged in a rainstorm. The circuit boards within the unit had been badly damaged due to a short circuit, but the general electrical flow of the device became clear, as did the parts required to build one from scratch. Primarily, a transformer and a large capacitor were needed to increase voltage and allow for the timed release of the charge through the fence circuit. Having already torn apart a microwave for parts to use in the Henmulator and having found both a large transformer and capacitor inside, I hypothesized that an electric fence charger could be constructed using these parts, paired with some sort of timing circuit which created short bursts of high-voltage, low current electricity, in the same way that commercial chargers do.

However, after assembling a rudimentary circuit from the salvaged microwave components, I realized that the voltage output from these devices was inappropriate for the application of the
fence charger. The capacitance of the microwave capacitor was too low, and the coil ratio of the transformer was too great, meaning that depending on the power source, the energizer would either put out too low a voltage to dissuade animals away from it, or produce such a high voltage and current that the unit would be potentially lethal to anything that touched it.

The design of a more complex circuit to mitigate these issues was explored, but without appropriate training in electrical engineering and the desire to keep this project as practical for farmers as possible, the experiment shifted direction. Two different plans for homemade electric fence chargers, with their designs and circuit diagrams made publicly available by their owners, were found online. Both plans centered on the use of salvaged automotive ignition coils. After comparing them for simplicity, one was selected that was originally published in the July 1982 edition of Mother Earth News and made available through the magazine’s website. Assembly involved the purchase of a few semi-conductor components, which were affixed to a homemade,

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Table 2.2. Purchased components for the Fence Charger. Prices based on radioshack.com retail prices, March 2015.
single-layer circuit board. The module was then wired to the car ignition coil, placed in a protective housing, and powered by a 12-volt lead acid battery.

Results

Although the attempt to design a fence charger from scratch was unsuccessful, the process of searching the web for a potential project, downloading plans and assembling likely resembles the workflow that many farmers searching for open-source technology will encounter, and is therefore highly relevant to this line of research. Initial construction of this project took only a few hours, the bulk of which involved laser etching paint off of a copper board to create a homemade printed circuit board. The cost of the components was relatively low as well, as the starter coil was salvaged from an old automobile.

That I, with only hobbyist level electronics experience, was able to make a functioning electric fence charger for only 56 dollars, speaks to the potential for projects like this to make an impact for farmer self-reliance and cost-efficiency. Further experimentation with the charger and pastured animals will be required to judge whether this particular model is a long-term solution for Jacob Springs Farm’s fencing needs, but as a proof of concept for decentralized farm technology, it is highly effective.
Regarding External Documentation

Without detailed documentation, much of the work accomplished on these projects would be difficult for uninitiated individuals to replicate and improve upon. Earlier this year, the Jacob Springs Farm team began developing a community wiki, called the Regenerative Agriculture Wiki (RAW) to share the farm’s philosophy, techniques and logistical details. I chose to post the plans and diagrams for the projects developed in this thesis on that wiki for three reasons. First, the wiki format, built on the open-source MediaWiki platform, allows for collaborative, real-time editing of the content, meaning that other people can participate in and improve the content of the site. Secondly, these projects will live on at Jacob Springs far beyond the completion of this thesis, and it will be important for farm team members specifically to find information about these projects for improvement and modification purposes. Lastly, the RAW is already hosted online and available from via the worldwide web, reducing the additional work required with purchasing server space and hosting for a new site.

From the RAW, users can investigate and download plans for projects, contribute to ongoing discussions about farm technology, and hopefully even upload projects of their own to share with the community at large. Additionally, there is a growing library of articles related to animal husbandry, pasture management, farm business practices, and other agricultural topics. Currently the site is relatively sparse, as the projects completed are minimal and the involved community is limited to the individuals that work on Jacob Springs Farm. It is my hope, however, that this site will continue to evolve as my work beyond this thesis continues. A link to the prototype of the Regenerative Agriculture Wiki, along with links to the code associated with the project, can be found in Appendix B.
Discussion/Closing Thoughts

In the face of the social and environmental challenges of the twenty-first century, agriculture must find new ways to improve and adapt to conditions. Although a plurality of solutions will be required to overcome these challenges, reframing our technological outlook in relation to agriculture is a critical piece of the puzzle. The projects explored in this thesis represent a fraction of the preliminary work in the overall research surrounding alternative farm technology development. The potential benefits exhibited by those projects—reducing cost, maintaining control over design and use, sustainable reuse and recycling of materials—must be weighed against the time and interest required on the part of the end user: will a farmer have the time or desire to contribute to an open-source hardware project? Does the technological knowledge base exist for a community of agriculturally minded inventors to start collaborating on new solutions to farm problems? Can openly developed, do-it-yourself products compete with commercial equivalents in terms of durability and reliability? These questions must be explored systematically to provide compelling evidence for the efficacy of new farm technology. Currently, the structures of knowledge available to those farmers who are interested in alternatives are limited primarily to conventional approaches, dominated by established agribusiness interests. Although it is more aligned with these interests, the Land Grant University system and agricultural extension service still represent a robust network for agricultural innovation, and a re-envisioned extension service, working as a laboratory for free and open farm technology, could have immense potential to revolutionize farm technology development. I recommend that standing policy regarding the funding and organization of Land Grant Universities and extension services be revisited. If it is a civic priority to create sustainable agricultural technology that reduces farmer burden and produces food efficiently without damage to the environment,
this network of institutions needs to be leveraged to this end, rather than maintaining the status quo.

In the event that the extension service does not fill this void, however, community organizations, like those that rose in response to the lack of institutional agroecological research at land grant universities, will have to rise to the challenge if a new era of “open agriculture” is to take root. While the government certainly has a role to play in helping shape sustainable farm policy, the decentralized nature of open-source means that an empowered movement of citizen engineers, passionate about sustainable agriculture, can start driving meaningful change now. I believe that the future of sustainable, open-source farm technology depends on it.
Appendix A: Potential farm technology projects

This appendix contains the comprehensive list of the project proposed as experiments during the planning stages of the thesis, along with my conceptual sketches from the planning phase.

Wireless Water Monitor

A device to monitor the level of water in stock tanks and storage reservoirs. This device would monitor the level of water in a given vessel, report that status wirelessly to the farm, and potentially activate a well pump to refill the vessel.
Humidity and Temperature Control Unit

Encapsulated sensor kit that could be used in a greenhouse, incubator, or other climate controlled environment. Uses 120V AC relays for controlling lamps, heaters, humidifiers, etc. This was utilized in the Henmulator.
Egg Reporter

Farm eggs are kept in a self-service pay station in the front of the farmhouse. Oftentimes, customers visit the farm for eggs only to find that eggs are out of stock. This would use a scale and wi-fi enabled microcontroller to submit feedback to a website that updates the status of the egg bin, along with providing useful information to customer about the farm’s egg program. It could also trigger an illuminated sign, like the one used on motel vacancy signs.
Automated Gate System

An extensive automatic gate system that would be set up in conjunction with a large pasture, divided into plots by an electric fence tape. A control module located within the perimeter fence charger would send signals to the fence modules, and water troughs would drain and fill to signal to livestock that they should change pasture. Then, after an interval of time (or some other monitoring system, such as a mounted optical camera or GPS tags on each animal), the gate would tighten and shut, keeping the animals in their new pasture. This would continue until the animals had moved through the entire pasture.
Soil Moisture Monitor

A small, self-contained unit would have two conductive legs that would be pressed into the soil. When the soil is moist, a circuit would be made across the legs, sending a radio frequency signal to a main control module, which could trigger irrigation gates, send notifications to the farmer, or simply record soil moisture levels. This system would involve a large number of these sensors being placed throughout a field.
Solar Powered Chicken Door

To protect chickens from predators when they are on pasture, an automatic chicken door that opens at sunrise and closes when the sun goes down could be installed on a mobile chicken enclosure. A stepper motor would wind up a cable attached to the door, and a small solar panel and rechargeable battery would power the motor. Additional features might include a disturbance sensor that notifies the farmer if something is moving the door after hours, or that triggers a sound to scare away predators.

Modular Internet of Things (IoT) system on the farm

An interconnected system could theoretically control all the devices and projects listed above. Three individual modules would function together in tandem to monitor, record and accomplish tasks on the farm. Ideally, a large, low-power radio frequency unit would broadcast a signal to the entire farm, communicating with a number of sensors and actuators around the farm. A central software platform would enable the recording of data, programming of system behavior, user alerts, etc.
Modular Farm Automation System Diagram.

**Sensors**
- Temperature
- pH
- Soil Moisture
- Water Level
- Humidity
- Power flow
- Animal counters
- Optical Sensors
- Motion
- Proximity

**Actuators**
- Power Flow
- Motors
- Light Control
- Security Systems (animal & human)

**Processor**

**Data Collected**
- Watering Records
- Local Temp Records
- What fences are on
- Potential breakdowns
- Potential feed/water issues
- Threat detection
- Behavioral tracking

**Data Provided**
- Behavioral Algorithms
- Feed/water schedules
- Irrigation schedules
- Historical weather data
- ITTT Programs
- Crop prices
- Storm warnings

**User Interface**
- Web/smartphone based
- Two modes- basic and advanced
- Issues Alerts

**Allows users to**
- Read data
- Write “if this, then that” style programs
- Schedule actions
- Set triggers
- Collect other farm data
- Create visual reports
Appendix B: List of hyperlinks to repositories for project plans and code

The Regenerative Agriculture Wiki (RAW): http://wiki.jacobsprings.com

Arduino Code for the Henmulator: http://pastebin.com/YW2PtA33

Works Cited


Carlson, A. Agrarianism reborn: On the curious return of the small family farm.


