Electrified Agriculture: Best Practice Guide for Farmers

Prepared for:

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DEFINITIONS

Automation: Technology by which a process is performed with minimal human assistance or interaction.

Electrification: The conversion of a machine or system to electrical power.

INTRODUCTION

This document highlights best practices and considerations for farmers as they prepare for the electrification and automation of the agriculture sector. Electrification and automation are symbiotic and linked in practice and adoption. The guide is meant to be a resource for farmers, enabling them to start conversations with interested parties toward key paths to electrification and automation. Best efforts were put forth to create an accurate and useful document, which discusses the general technical details of electrification and automation in agriculture. The pursuit of electrification and automation should be made with qualified professionals experienced in these fields. Additionally, this guide presents an unbiased approach to the different methods of electrification.

The guide has three sections. First is an overview containing a high-level view of electrification opportunities in agriculture. Second is an electrification section with a detailed description of electrification at the farm level, the best technologies available (including pros, cons, and considerations), the current adoption rate of electrification, why more producers should pursue electrification, and solutions for overcoming barriers to adoption. And third is an automation section with a detailed description of automation at the farm level, the best technologies available (including pros, cons, and considerations), the current adoption rate of automation, why more producers should pursue automation, and solutions for overcoming barriers to adoption.

These are the key takeaways:

- Many electrification technologies currently exist, but only a few are commercially available and ready for widespread implementation.
- A select few technologies are fully developed (e.g., electric irrigation pumps and water heaters) and ready to be proliferated through the market; these should be pursued by all producers.
- Opportunities exist for producers to increase profitability and future-proof operations by electrifying equipment.
- When coupled with self-generation, electrification offers a self-contained energy solution that can fix input costs.
- Opportunities currently exist for agricultural task automation, especially with livestock.
- Regulations are currently a limitation to further automating agricultural processes.

1. OVERVIEW OF THE ELECTRIFICATION OF AGRICULTURE

Electrification has been a driver of increased productivity and quality of life since the passage of the *Rural Electrification Act* in 1936.[1] Despite spatial and technological barriers, rural electrification occurred at a fast pace. The widespread adoption of initial electrification, going from nearly 90% of farms lacking electricity in 1930 to 93% of farms having electricity just a few decades later,[2] provides insights for the next technological revolution in agriculture—the electrification and automation of equipment and processes. There are many benefits to producers who implement electrification and automation, including the stabilization of input costs, increased farm resilience, and a decreased physical and mental workload.

Non-energy benefits are one of the most important categories of electrification benefits to producers. Utilities use the term "non-energy benefits" to describe ancillary costs and benefits to energy efficiency, but the term can also be used to describe ancillary benefits for producers pursuing electrification. While electrification offers its own non-energy benefits, these compound when coupled with the pursuit of automation. In farming, a major non-energy benefit of both electrification and automation is decreasing the physical and mental health strain on farmers and laborers. For example, maintenance of diesel engines and motors can result in downtime and can seriously impact both business productivity and physical health. While electric motors may require occasional maintenance, reliability is higher compared to diesel and the motor's fuel comes from the grid, not from liquid fuels that must be transported and ultimately distributed by labor. While GPS on tractors have already reduced the real-time human inputs associated with tractor operation, fully electric and automated tractors would further reduce the reliance on labor. With farm labor pools shrinking, electrification and automation offer a solution for these issues by removing that need.

Electrification offers an increased resilience over fossil fuel-based systems not only through increased reliability when compared directly but also through the ability to run on any generation source. For example, once fully transitioned to electrification, it does not matter what source the electricity comes from, be it a natural gas utility or cooperative-owned generation plants, or utility- or farmer-owned wind, solar, and battery storage. With this transition, future changes in energy markets can be more easily remediated and a continuous, reliable source of electricity can be found, as opposed to using finite energy sources such as fossil fuels.

Electrification also allows for the stabilization of input prices. Rather than being subject to fluctuating fuel price markets that impact margins and profitability in the traditional fossil fuel-based input model of agriculture, electrification offers an opportunity to stabilize prices. Farmers can better know their input costs by cultivating a direct relationship with the local utility, or by self-generating electricity. Electrification also allows for future opportunities to increase efficiency, providing even more opportunity for savings on inputs.

Once fully electrified, farms can potentially participate in the grid as a distributed energy resource if they self-generate their power. For example, an 8,000-head swine operation in North Carolina installed a waste lagoon and biodigester that powers a 180 kW generator.[3] The farm has entered into a power purchase agreement with its local power provider and sells excess generated power back into the grid.

Table 1 summarizes existing electrification technologies based on existing research and is an excellent starting point for understanding what may be available for the agricultural segment.

[1] Rural Electrification Act of 1936, Pub. L. No. 74-605, 49 Stat. 1362 (1936).

[2] Kline, Ronald R., "Resisting Development, Reinventing Modernity: Rural Electrification in the United States before World War II." *Environmental Values* 11, no. 3, (2002): 327-344, http://environmentandsociety.org/node/5860.

[3] Larson, A., *Distributed Energy Award Goes to Unique Hog Farm Microgrid*, 2019, https://www.powermag.com/distributed-energy-award-goes-to-unique-hog-farm-microgrid/?pagenum=2.

Table 1. Overview of Farm Beneficial Electrification Technologies

Electric Technology	Primary Farm Types	Commercialization Status	Agricultural Market Penetration
Irrigation pumps	Orchards, vegetables, field crops	Available, widespread	High
Water heaters	Dairy	Available, widespread	Medium
Grain dryers	Field crops	Early, only small capacity	Very low
Maple sap evaporators	Maple	Available, limited selection	Very low
Thermal electric storage systems	Poultry, swine, greenhouse	Available, limited selection	Very low
Radiant heaters	Poultry, swine, greenhouse	Early, only small capacity	Very low
Heat pumps	Greenhouse	Early	Very low
Heat exchangers	Poultry, swine, greenhouse	Available	Very low
Tractors	All, especially field crops	Very early, not available	None

Source: Clark, K., Farm Beneficial Electrification: Opportunities and Strategies for Rural Electric Cooperatives, National Rural Electric Cooperative Association, 2018, https://www.cooperative.com/programs-services/bts/documents/techsurveillance/surveillance-article-farm-beneficial-electrification-october-2018.pdf.

2. BEST PRACTICES IN ELECTRIFICATION

Electrification in agriculture has led to many beneficial developments, from the initial electrification of rural areas to current electrification trends offering solutions for the problems producers face. Technological advancements are moving agricultural practices toward the replacement of fossil fuel inputs with purchased or self-generated electricity. Ultimately, electrification moves producers away from fossil fuels and toward a cleaner, more reliable source of power.

Electrification can transform every segment of agriculture, from field crops with tractors and irrigation pumps to livestock with water and space heating. While barriers to implementation exist, these can be overcome with further technological development, incentivization, and education.

One of the major barriers to electrification in agriculture is the initial capital investment. Table 2 presents U.S. Department of Agriculture (USDA) programs that may be applicable for producers looking to electrify equipment or for utilities looking to incentivize the electrification of equipment on farms. Producers may also want to investigate additional local incentives through other organizations or potential incentives from utilities/cooperatives.

Table 2. Key USDA Programs Applicable to Farm Beneficial Electrification.

Program	Rural Energy Savings Program (RESP)[1]	Rural Business Development Grant (RBDG)	Rural Energy for America Program (REAP)	Environmental Quality Incentives Program (EQIP)
Summary Description	Provides zero-interest loans to entities providing rural power to re-lend to consumers	Competitive grant designed to support small business in rural areas	Provides loan and grant funding to rural small business to make energy efficiency improvements	Provides incentives for on-farm practices that address natural resource concerns, including air quality and energy use
Eligible Area	Any area served by an entity that is an eligible borrower from rural utility service	City or town with a population of less than 50,000	City or town with a population of less than 50,000	Any
Use of Funds	Implement measures that save energy or energy costs incurred by qualified customers, energy audits	Acquisition of machinery, equipment, utilities, energy audits	Energy efficiency, greenhouse gas reduction, and renewable energy projects	Energy efficiency improvements, including fossil-fuel-to-electric motor conversions, energy audits

Program	Rural Energy Savings Program (RESP)[1]	Rural Business Development Grant (RBDG)	Rural Energy for America Program (REAP)	Environmental Quality Incentives Program (EQIP)
Incentive Terms	20-year, 0% interest loans for relending at interest rates up to 3%; Maximum loan amount subject to credit review	No maximum grant amount	Loans up to $25 million, 85% loan guarantee, 15 years Grants up to 25% of project cost up to $250,000 for energy efficiency projects and up to $500,000 for renewable projects	Incentives and incentivized measures vary by state but generally cover 50%-90% of project costs
Who May Apply?	Rural electric cooperatives	Rural electric cooperatives	Farms and small rural businesses (energy audit required)	Farms (energy audit required)

[1]RESP is similar to the Energy Efficiency Conservation Loan Program, also offered by the USDA Rural Development.
Source: Clark, Farm Beneficial Electrification

The following sections present additional examples of opportunities for electrification within the field crops, livestock, and specialty crops/horticultural sectors.

2.1 Field Crops

The technologies most applicable to field crops include irrigation pumps and heavy machinery. While many technologies are still in the research and development (R&D) phase, there are opportunities for field crop producers to electrify immediately and save costs over the long run.

The electrification of irrigation pumps is a widespread phenomenon that has occurred over the past three decades; there is an opportunity to completely electrify this input and save producers costs while reducing environmental impacts. For example, switching from an irrigation pump powered by diesel (with 40% efficiency) to a pump powered by electricity (with 95% efficiency) can dramatically reduce both input costs (diesel-driven motors can cost up to twice as much to run like an electric motor) and environmental impacts (emission reduction of 75.7% using traditionally generated electricity).[4]

The electrification of heavy machinery and tractors is a revolutionary transformation that is in its early stages. Currently, there are no commercially available options for fully electric tractors, but prototypes do exist, and multiple major manufacturers are researching and developing the technology. Tractors are the single largest opportunity for electrification in agriculture, with over 28,000 GWh being estimated to be needed to fully electrify the tractor fleet in the U.S.[5]

[4] Clamp, A., *Farm Irrigation Systems,* National Rural Electric Cooperative Association, 2017, https://www.cooperative.com/programs-services/bts/Documents/TechSurveillance/tsbecasestudyirrigationsystemsdec2017.pdf.
[5] Clark, K., *Farm Beneficial Electrification: Opportunities and Strategies for Rural Electric Cooperatives*, National Rural Electric Cooperative Association, 2018, https://www.cooperative.com/programs-services/bts/documents/techsurveillance/surveillance-article-farm-beneficial-electrification-october-2018.pdf.

Grain dryers remove moisture and create safe, long-term crop storage but can be a very energy-intensive step. Energy use per bushel varies based on moisture content and type/model of grain dryer. However, one example estimates that for a gas-fired dryer, 0.02 gallons of liquid petroleum gas (LPG) is needed per bushel per percentage point of moisture removed.[6] Assuming LPG costs $2.00/gallon, drying corn from 21% to 16% moisture results in a fuel input cost of $0.20 per bushel. This cost can be directly compared to kilowatt-hour costs for an electrical option. Although the electrification of grain drying is a developing market under research, few commercial options exist. A no-heat and low-temperature dryer can be used in grain drying that only uses electricity, but at this point, electricity is a higher cost per amount of energy than propane or natural gas, so these types of dryers are more expensive to run.[7] However, the economics of electricity change if there is onsite renewable generation, so this option may be economical for some producers.

2.1.1 Electric Irrigation Pumps

The electrification of irrigation pumps may not be as innovative as it was three decades ago, but the opportunity exists to completely electrify this input. This would save farmers' costs while reducing environmental impacts. One USDA estimate states there are over 175,000 fossil fuel-powered irrigation pumps in the U.S.[8] While this represents a massive potential for electrification and a reduction in environmental impact, there is a financial opportunity on the individual farm level.

Source: Peter Gonzalez on Unsplash

For example, a 130-acre center-pivot irrigation field that pumps water from 150 feet at 50 PSI results in a potential savings of over $4,000 in energy costs. Savings is dependent on current fuel prices and electricity rates. More detail about potential scenarios can be seen in Table 3.

Table 3. Annual Savings by Using Electricity

Electricity		Diesel Fuel Cost, $/Gallon 1.75	2.00	2.25	2.50
Price, $/kWh	**Total Annual Costs**	$19,616	$20,625	$21,634	$22,643
0.06	$18,549	$1,067	$2,076	$3,085	$4,094
0.07	$19,119	$497	$1,506	$2,515	$3,524
0.08	$19,689	-$73	$936	$1,945	$2,954
0.09	$20,259	-$643	$366	$1,375	$2,384
0.10	$20,829	-$1,213	-$204	$805	$1,814

Source: Martin et al., Evaluating Energy Use for Pumping Irrigation Water

[6] Wilcke, W., *Energy Costs for Corn Drying and Cooling*, 2018, https://extension.umn.edu/corn-harvest/energy-costs-corn-drying-and-cooling.
[7] Dyck, J., *Reducing Energy Use in Grain Dryers*, 2017, http://www.omafra.gov.on.ca/english/engineer/facts/17-001.htm.
[8] Clark, K., *Farm Beneficial Electrification: Opportunities and Strategies for Rural Electric Cooperatives*, National Rural Electric Cooperative Association, 2018, https://www.cooperative.com/programs-services/bts/documents/techsurveillance/surveillance-article-farm-beneficial-electrification-october-2018.pdf.

In addition to the savings based on energy costs, the electrification of irrigation pumps presents an opportunity to save on labor. The move away from fossil fuels removes the need to refuel as well as various other maintenance tasks and is a step toward automation. Electrified irrigation can take place outside of peak hours, potentially increasing energy savings if the farm is on a time-of-use contract with its energy provider.

Differences in rural and urban agricultural practices may be seen with the adoption of electric irrigation pumps. Electricity is more accessible in an urban farming context and may be the only option given local zoning laws against noise and pollution. Urban farming may take place as a hydroponic or aquaculture operation, which would require reliability and consistency that can be offered by electricity-powered irrigation.

Infrastructure is a barrier to the electrification of agricultural irrigation systems in both in a capacity sense and a physical sense. Regarding capacity, estimates that if all fossil fuel-powered irrigation pumps were electrified, around 7,600 GWh would be needed to provide power, assuming an annual runtime of 940 hours and an average motor size of 87 horsepower.[9] An overnight shift requiring this amount of additional electricity would not be feasible but could be managed if a coordinated effort is made.

For physical infrastructure barriers, electrification of irrigation pumps traditionally would require three-phase power to be installed, typically at great capital expense. One estimate puts the cost per mile for a three-phase line from $50,000 to $150,000.[10] A potential solution is using a variable frequency drive so that single-phase power can be used for heavy machinery, such as an irrigation pump.

Initial capital cost is another potential barrier to the electrification of irrigation pumps. One way to address this barrier is to pursue grants or other programs that may be offering incentives for fossil-fuel-to-electric transitions. An example of an existing program is Delaware Electric Cooperative's (DEC) variable frequency drive (VFD) incentive program for irrigation pumps.[11] DEC provides grants to producers of up to $15,000 for electric motors over 40 horsepower but also assists in extending power lines to reach the irrigation pumps. A national example of overcoming capital expense barriers is the previously described Environmental Quality Incentives Program, which provides energy audits, after which eligible farmers may apply for funding assistance.[12]

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[9] Clark, K., *Farm Beneficial Electrification: Opportunities and Strategies for Rural Electric Cooperatives*, National Rural Electric Cooperative Association, 2018, https://www.cooperative.com/programs-services/bts/documents/techsurveillance/surveillance-article-farm-beneficial-electrification-october-2018.pdf.

[10] Clamp, A., *Farm Irrigation Systems,* National Rural Electric Cooperative Association, 2017, https://www.cooperative.com/programs-services/bts/Documents/TechSurveillance/tsbecasestudyirrigationsystemsdec2017.pdf.

[11] Clamp, *Farm Irrigation Systems*.

[12] Clark, *Farm Beneficial Electrification*.

2.1.2 Electric Tractors

Source: Scott Goodwill on Unsplash

Electrification of tractors and combines can offer farmers savings on energy costs over traditional fuel sources, especially when coupled with onsite renewable energy generation. Rather than purchasing diesel fuel from suppliers and being dependent on market prices, electricity can either be self-generated or negotiated and purchased from a local utility or cooperative. Options for self-generation vary by location and may include wind, solar, geothermal, and biodigesters.

A non-energy benefit of electric tractors is potential savings on labor due to reduced maintenance requirements as a result of higher reliability in electric motors compared to diesel. Additionally, the labor associated with refueling is saved when tractors are powered by electricity instead of fossil fuel.

Another benefit of tractor electrification is future-proofing a field crop operation. The transition toward electrification is accelerating in all vehicle classes, and farm equipment is beginning that process. Transitioning away from fossil fuels provides more flexibility in an uncertain future with regards to the environment, regulation, and fuel availability. Electric tractors and combines could run on any generation source, whether it be traditional sources of utility electricity (e.g., coal, natural gas, nuclear) or renewables (e.g., wind, solar, biofuels).

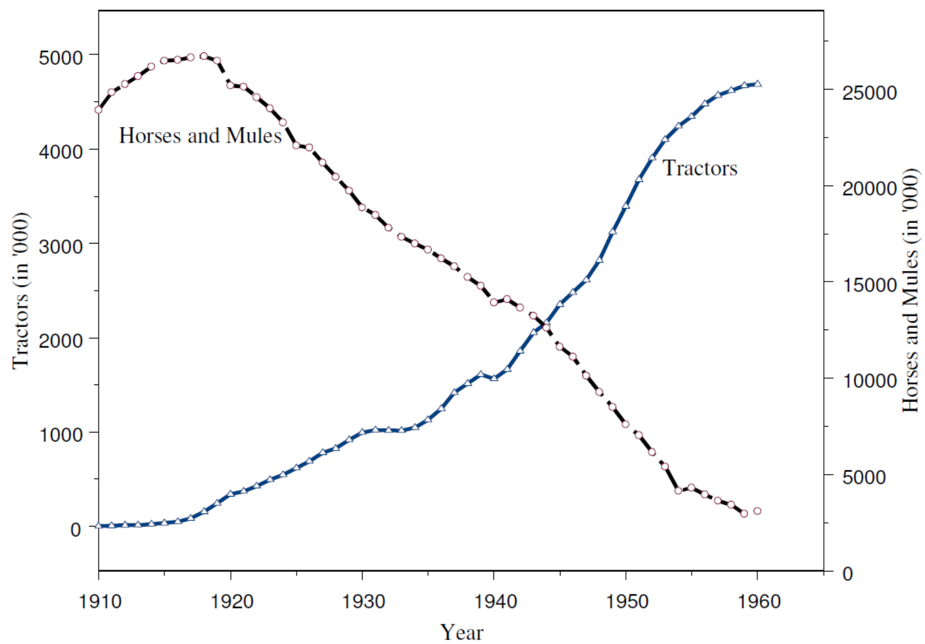
While the electrification of tractors offers a flexible and advantageous future for field crop farming, the major barrier for this progression is initial capital cost. Field crop farmers are increasingly leasing equipment rather than buying to keep up with current technology developments (e.g., GPS systems), so once fully electric tractors and combines are available, it is logical that leasing would be an entry point into the market and may ease the barrier of immediate obsolescence of current equipment if one lease is traded in for another. Another option for reducing or removing the capital cost barrier is for utilities/cooperatives or the government to work with manufacturers to incentivize the adoption of electric tractors.

Another potential barrier to the adoption of electric tractors and combines is familiarity and tradition with incumbent equipment. Producers may feel that knowing how to deal with diesel engine issues outweighs the potential benefits and potential unknown issues with an electric motor. Initial reluctance to adopt is understandable, and as with any technological advancement, will need to be addressed through a strong coordinated educational approach, from organizations such as tractor manufacturers, NEMA, and Cooperative Extension.

Infrastructure limitations represent a practical barrier to the adoption of electric tractors. Large electric motors require a large capacity to power tractors and ancillary equipment, and this capacity may not exist at the point which it would be needed. This assumes a plugged-in model of electric tractors with a self-managing cord system. The battery pack model of electric tractors would need to be charged and could need to be plugged in during off-peak times. The capacity of batteries would also need to increase so producers can use the tractor all day without recharging. If current battery-powered prototypes are commercialized, they may be a more realistic option for smaller or urban farming, where sizes of plots are not as limiting on battery range and recharging infrastructure. Producers will need to work closely with their local power provider to ensure the capacity exists within the existing infrastructure and to negotiate rates and be cognizant of time of use.

Although there are prototype electric tractors by multiple manufacturers, widespread availability is not reality. The future adoption curve for electric tractors is unknown at this point. However, the transition from horses and mules to mechanical tractors in the past provides a good example (see Figure 1).

Figure 1. Horses, Mules, and Tractors in Farms, 1910-1960



Source: Manuelli, Rodolfo E. and Ananth Seshadri, "Frictionless Technology Diffusion: The Case of Tractors"

Initially, there was resistance to a modal change in farming operations from horses to tractors, but the eventual transition to tractors resulted in large productivity advances. The same pattern could occur with the electrification of tractors, but the widespread availability and accessibility of educational information may help advance the adoption curve of electric tractors at a faster rate than the transition from animal power to mechanical power.

2.2 Livestock

While large opportunities exist for electrification in field crop farming, equally large opportunities exist in livestock farming. Many of the livestock electrification opportunities also lead to automation in processes. This section discusses the opportunities for drone technology, water heating, and space heating.

2.2.1 Drone Technology

Drone technology represents a significant immediate opportunity for electrification in livestock farming. While not a direct electrification of existing technology, using drones can reduce the need for a producer to travel their land physically. The ability to remotely view areas around the property without driving a truck or other vehicle saves on fuel costs and decreases environmental impact. With the costs of a sophisticated drone being a few thousand dollars and dropping, this technology can appeal to producers by offering a quick payback through reduced wear and tear on other farm vehicles in addition to reduced labor costs. Current drone technology requires a direct line-of-sight between pilot and aircraft but offers multiple possibilities for helping producers reduce their physical labor. Herd health, water supply, and fence integrity monitoring are potential uses for livestock producers. Weather condition sensing, such as temperature and moisture saturation, and imagery of growth and post-fertilization realized application rate are all potential uses for field crop producers.

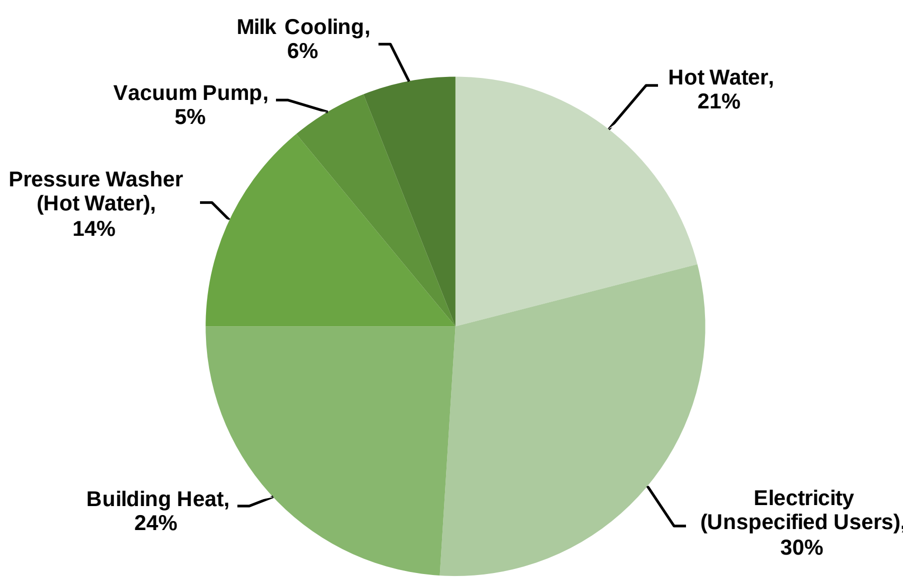
2.2.2 Electric Space Heating

Space heating is a large input cost for livestock producers. For example, each broiler chicken is estimated to require 2,808 Btu of heat over its lifetime. Fully electrifying chicken operations would require an estimated 4,755 GWh of energy for those operations currently served by cooperatives. This number does not include operations served by commercial utilities and does not include other livestock operations that require space heating, which represents another potential 5,300 GWh of energy.[13] Although commercial and industrial rated electric heaters exist, the infrastructure requirements (three-phase power source) or energy consumption make them less competitive with traditionally fueled heating systems. However, when coupled with a self-generation system of electrical power, the electrification of heating systems could be a large opportunity for livestock producers to be self-sustaining and to minimize inputs external to the operation. Any effort to electrify space heating on a large scale should be discussed with a local power provider, as capacity must be in place prior to its installation.

2.2.3 Dairy Water Heating

A large input of resources in the dairy industry is water heating and milk cooling. Dairy water heating is one opportunity for beneficial electrification in livestock farming; it includes not only heating water for sanitation of milk lines and holding tanks, but also chilling milk, moving water, and cleaning. According to the University of Minnesota research, over 20% of the energy used on a dairy is for water heating. Figure 2 shows the energy use in dairy milking operations.

Figure 2. Energy Use in Milking Operations



Source: Tate, T., Agribusiness

[13] Clark, K., *Farm Beneficial Electrification: Opportunities and Strategies for Rural Electric Cooperatives*, National Rural Electric Cooperative Association, 2018, https://www.cooperative.com/programs-services/bts/documents/techsurveillance/surveillance-article-farm-beneficial-electrification-october-2018.pdf.

A large dairy farm could see immediate benefits switching from fossil fuel-based water heating systems to a heat pump system, with a payback period of fewer than three years. An alternative to installing a heat pump system is an integrated chiller system. For example, in a 4,000-head dairy farm, once an integrated chiller system is installed, it eliminated propane use for hot water production, saving $25,000 on propane and an additional $5,000 on electricity. This results in a payback period, similar to a heat pump system of fewer than three years.[14]

Readily available technology such as VFDs, heat exchangers, heat pumps, and chillers can significantly improve efficiency and allow for fully electric operation. For example, costs are $85,890 for a commercially available system for an industrial chiller with an integrated heat recovery system. This system was installed on a 4,000 head dairy operation providing over 5,000 gallons of hot water available for cleaning. The system eliminated propane use for producing hot water at a savings of $25,000/year. Additionally, increasing electrical efficiency saved $5,000/year on electrical expenses, giving a payback period of 2.86 years.[15] Equipment efficiency improvements for this process are in Table 4.

The chiller system could also avoid the production of a significant amount of emissions. Converting units, the system saved $25,000 in propane costs and assuming $1.99/gallon for propane, that is approximately 13,158 gallons of propane saved. Assuming 4.2 pounds of propane per gallon, that is 55,263 pounds of propane saved. There are 18 pounds of propane in a cylinder, so it would be 3,070 cylinders. Converting using the US Environmental Protection Agency formula:

18 pounds propane/1 cylinder
x 0.817 pounds C/pound propane
x 0.4536 kilograms/pound
x 44 kg CO_2/12 kg C
x 1 metric ton/1,000 kg
=0.024 metric tons CO_2/cylinder

The system described previously would save 0.024 x 3,070 = 73.68 metric tons of CO_2 emissions saved.

Table 4. Current Dairy Equipment and Electrification Alternatives

Equipment	Percent Energy Use	Alternative Technology	Benefits
Vacuum pump	20-25	VFD	Reduce energy operating costs up to 60%, extend pump life with lower RPM
Precool milk direct, in-tank cooling	>50	Indirect heat exchange, precooling	Reduce milk temps up to 40°F, save up to 60% of cooling costs, milk temp from cows 95°F-99°F, the target is 38°F
Water heaters/storage	25	Insulation, heat exchangers	Reduce heat loss by up to 3% and thereby operating costs
Refrigerant and cleaning line heat loss	NA	Insulation	Reduce heat loss by up to 3% and thereby operating costs

Source: Tate, T., Agribusiness

[14] Tate, T., *Agribusiness: Dairy Water Heating. National Rural Electric Cooperative Association*, 2018, https://www.cooperative.com/programs-services/bts/Documents/TechSurveillance/TS-Beneficial-Electrification-Dairy-Water-Heating-April-2018.pdf.

[15] Tate, *Agribusiness.*

2.3 Specialty Crops

Producers that do not fit under the traditional field crop or livestock label have opportunities to pursue electrification. There are large potential benefits in this sector, with greenhouse system electrification representing the largest opportunity, especially when coupled with self-generation of electricity.

2.3.1 Greenhouse Electrification

Second only to tractors, greenhouse space heating electrification is a huge opportunity with an estimated 14,000 GWh to over 20,000 GWh needed to replace the fossil fuel heating needs of specialty crop producers.[16]

Source: Daniel Fazio on Unsplash

Greenhouse space heating energy usage is anticipated to increase as operations such as hydroponic/aquaponic agricultural production continues to grow in popularity, and as cannabis legalization expands. Thermal electric storage systems exist but manufacturing is limited and costs are currently high. The situation is similar to electric radiant heaters, heat pumps, and heat exchangers, where options do exist, but choices are limited. Producers interested in electrifying their space heating should consult an electrical professional to ensure the appropriate load infrastructure is in place prior to connecting electric heaters to the grid. Greenhouse operators could stabilize input costs that might be particularly volatile in winter months when fuel demand is high. If desired, self-generation via renewables coupled with energy storage could allow greenhouse operators to become self-reliant for energy needs, and could potentially participate in the grid as a distributed energy resource. Even if self-generation is not installed, a storage system could potentially decrease costs as energy could be purchased during off-peak times and stored to be used during peak times.

Overall, the growth of indoor agriculture, especially in urban areas, is expected to increase, along with electricity use for indoor food production by using artificial instead of natural light. Farming indoors carries several advantages over traditional agriculture, including resilient year-round production in any climate, no crop loss due to extreme weather events, minimal energy inputs for harvesting and transporting crops due to proximity to markets, minimal or no use of pesticides and herbicides, using up to 70% less water inputs than traditional farming, increased food safety, and increased food security.[17]

2.3.2 Maple Sap Evaporation

A unique specialty crop opportunity for electrification lies in maple syrup production. Typical energy costs for sap concentration into syrup account for 26%-34% of the production costs and electric evaporation for syrup production appears to be catching on with producers. Electric input costs with a commercially

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[16] Clark, K., *Farm Beneficial Electrification: Opportunities and Strategies for Rural Electric Cooperatives*, National Rural Electric Cooperative Association, 2018, https://www.cooperative.com/programs-services/bts/documents/techsurveillance/surveillance-article-farm-beneficial-electrification-october-2018.pdf.

[17] Despommier, D., *The Vertical Farm: Controlled Environment Agriculture Carried Out in Tall Buildings Would Create Greater Food Safety and Security for Large Urban Populations,* 2011. https://link.springer.com/article/10.1007%2Fs00003-010-0654-3?LI=true.

available electric system are estimated to be $0.21/gallon of syrup, drastically cutting production costs.[18] Initial capital costs for an electric evaporator is around $50,000, but there may be a reasonable payback period with significantly lower production costs and other benefits. Grants and other utility incentives also may exist, depending on the area. Contact a local extension professional or talk to a utility representative to figure out if any programs exist.

[18] Gregg, P., *EcoVap Electric Evaporator Catching On*, 2014, https://www.themaplenews.com/story/ecovap-electric-evaporator-catching-on/64/.

3. BEST PRACTICES IN AUTOMATION

Automation in agriculture has already led to many beneficial technologies for producers, and it is still in its infancy. GPS technology guides tractors through rows and has the potential in the near future to remove all labor requirements for plowing, planting, fertilizing, and harvesting. With automation, the field crop producer will move from a position of physical laborer to that of a manager, overseeing systems, optimizing automated processes, and troubleshooting any imperfect technology. Automation technologies also have the potential to greatly reduce labor costs and increase efficiency in resource use.

Automation of livestock processes holds the potential for increasing production while also increasing animal happiness and decreasing labor costs. When coupled with electrification and potentially self-generation via renewables, livestock producers can significantly decrease potential environmental impacts and stabilize input costs.

Specialty agriculture also can benefit from automation, allowing for targeted precision with crops sensitive to temperature or moisture while also optimizing nutrient input to maximize yields. Automation can also remove one of the highest costs for specialty agriculture: labor. With current agricultural labor shortages only projected to increase, automation offers a long-term solution.

One of the major barriers to automation is the current regulatory environment. Hopefully, progress can be made toward enabling innovation and finding a regulatory compromise that allows producers to pursue these new technologies. The following sections present additional examples of opportunities for automation within the field crops sector, livestock sector, and specialty crops/horticultural sector.

3.1 Field Crops

Automation could revolutionize field crop production. While some technologies already exist, the future holds a wealth of potential for automating field crop processes. These technologies could increase crop yields with precision agriculture, increase producer safety by limiting implement interaction, and decrease physical labor load. The following sections detail self-driving automated tractors (a future technology currently under research), along with automated irrigation and drone technology (two readily implementable automation solutions).

3.1.1 Self-Driving Tractors

Although GPS-guided tractors are commonplace in current field crop production, the next step is fully automated tractors and combines. Fully-automated tractors and combines would move around land plowing or planting or harvesting. This removes the need for a producer to ride in a tractor cab, freeing up time to analyze crop data, troubleshoot, or provide maintenance to other areas of producer operations. Automation could also save on energy costs by calculating and using the most efficient path possible to work fields. Automation and precision could save on energy costs and fully automated tractors save on potential labor costs. With agricultural labor shortages showing no sign of alleviation, automation offers a potential solution. Combined with electrification, automated tractors would also remove much of the maintenance and labor associated with tractor use and diesel engines, further reducing the labor need on farms.

The current and future regulation of automated vehicles is a major barrier to automated tractors. While not necessarily subject to public traffic laws while farming on private land, it remains to be seen how autonomous vehicles, not just tractors, will be regulated on public roads and how liability issues will be resolved. Fully automated tractors are being researched by various major manufacturers, but a timeline for their commercial release and subsequent diffusion within the marketplace remains unknown. This unknown timeline brings up another barrier, that of large capital investments. Like electrification of tractors, leasing fully automated tractors may be the entry point into the agricultural market, with diffusion taking place over subsequent years.

3.1.2 Automated Irrigation

More readily implementable and beneficial automation technology is automated irrigation through connected soil sensors and irrigation pumps. This technology can revolutionize irrigation operations and allow for greater precision and water conservation. Coupled with interconnected technology such as drones (Section 3.1.3), automated irrigation can provide producers automated real-time crop monitoring, improving yields by reducing water stress and optimizing the deployment of resources.

Source: Wynand Uys on Unsplash

It is likely that automated soil monitoring and irrigation will continue to grow exponentially, one estimate found a growth rate of over 16% year-over-year since 2015.[19] Many irrigation systems are already designed to move on their own if they are not fixed systems, so automation is a natural next step. Once automated, the determination of moisture needs will be monitored remotely by the producer and may not even need to be triggered by a human. Instead, it can automatically occur when soil sensors indicate irrigation would be maximally beneficial while also conserving resources and considering variables like time of use and weather forecasting.

A potential barrier to automating soil monitoring and irrigation processes is creating an Internet of Things system that is required for automated field monitoring. A reliable internet or cellular connection is required to connect automated soil monitoring systems to a user interface to interpret data, and some rural areas may still be without these connections. A solution would be to either create the network by incentivizing cellular or internet providers to build out rural broadband and cellular access, or by piggybacking on existing rural technology (such as real-time kinematic towers used for tractor GPS systems) to provide a network on which sensors can connect.

[19] Yadav, P. K., Sharma, F. C., Thao, T., and Goorahoo, D., *Soil Moisture Sensor-Based Irrigation Scheduling to Optimize Water Use Efficiency in Vegetables. Irrigation Association*, 2018, http://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2018/Soil_Moisture_Sensor-based_Irrigation_YADAV.pdf.

3.1.3 Drones

Source: Jared Brashier on Unsplash

In addition to being an opportunity for field crop automation, there are numerous potential applications for drones—assuming the regulatory environment shifts toward permission of automated flight.

Field crop monitoring could theoretically take place via drone as part of a partially or fully automated system. For example, soil sensors could tell a moisture monitoring system the specific local conditions, and a drone could be deployed to take photographs and collect other monitoring data that could be used to confirm the soil sensor findings. Weather monitoring is another potential drone application. While soil sensors can give readings around the soil level, drones could measure canopy growth, air temperature at canopy level, and possibly conduct weed monitoring. These readings can all be completed on an automated set schedule, which would give producers a wealth of data to analyze. Federal, state, and local regulations represent the top barrier to automating drones. Since in the agricultural context drones would be used for business purposes, current regulations require the operator to adhere to the Federal Aviation Administration rules for unmanned aircraft systems. It is not known what regulations will be enacted on automated drone systems in the future, but current regulations require a direct visual line-of-sight between the remote pilot and the drone, effectively restricting the implementation of automation. While beneficial for current agricultural operations, full automation for drones remains theoretical.

Drones could be beneficial not only for the automation of field crop operations but also for the management of livestock herds. Cattle ranchers currently use drones to monitor herd movements, find lost animals, monitor grazing land quality, and monitor water sources. Future applications are already being developed for autonomous herd counting, fence checking, and checking for animal health (such as detecting illness or breeding readiness). Similar applications for drones could be seen in dairy farms, or for sheep, goats, or any animal large enough to warrant an aerial monitoring system.

3.2 Livestock

Fundamental changes have taken place in livestock farming as a result of automation. Dairy producers no longer physically milk twice or thrice daily and are now systems operation managers, monitoring milk output and anticipating and preventing issues with herd health, all while increasing output. While automation will eventually touch all areas of livestock farming, this section presents two technologies in the context of dairies.

3.2.1 Robotic Dairy

One of the most successful automated technologies currently on the market for agriculture is a robotic milking system for dairy farms. Around one-third of total dairy operating expenditure is labor, and a large milking parlor can require up to six skilled workers for three shifts per day. This labor can be difficult to find, and filling open positions can become an expensive and continuous process. A robotic milking system can decrease total labor by around 75%, and drastically increase overall labor efficiency. Another benefit is an up to 10% increase in milk production by using the robotic milking system. Because there is a tracking device on each head in the herd, milk production can be monitored and cows can enter the milking area only when it is optimal for milk production. The system also monitors the health of the herd, and issues can be detected faster than with human labor.[20]

The initial capital cost for a single box robotic milking unit is over $200,000, but one unit can milk around 60 cows a day.[21] Financing can reduce the financial barrier, being that labor costs are replaced by the robot cost during payoff. The robot operates 24/7, 365 days a year, and can have a payback period of fewer than four years while having a realistic lifespan of over 20 years (Table 5 assumes an apples-to-apples comparison of systems with a 180-cow capacity).

Table 5. Cost Comparison of Robotic vs. Retrofit vs. Traditional Milking System

	Robotic Milking System (3x per Day) (New)	Robotic Milking System (3x per Day) (Retrofit)	Traditional Parlor Milking System (2x per Day)
Life Expectancy	20 years	20 years	20 years
Initial Cost	$214,500	$273,000	$85,800
Annual Electric Cost*	$1,080 at $0.06/kWh	$1,080 at $0.06/kWh	$570 at $0.06/kWh
Other Annual Cost**	-$12,780	-$12,780	$22,800
Total Lifetime Cost	-$19,500	$39,000	$553,200
Annual Average Cost	-$975	$1,950	$27,660

**Fuel prices are national averages based on price data from the US Energy Information Administration, http://www.eia.gov/. A robotic milking system consumes 18,000 kWh annually while the alternative consumes 9,500 kWh annually.*

***Includes maintenance costs, labor costs, energy for cooling the additional milk produced, and earnings from milk production; negative number is income.*

Source: Electric Power Research Institute (2016b), Robotic Milking System

The continual operation of robotic operation is both a barrier and a benefit. The continual operation creates the continual possibility of an issue that needs to be addressed by the producer. No longer constrained to two or three milking cycles per day, the producer is effectively on-call throughout the day to deal with any mechanical issues or herd health issues detected by the system.

The benefits far outweigh the costs. Although only an estimated 5% of dairy farms have robotic milking systems, the year-over-year growth is approaching 25%, meaning that producers that are not considering this technology risk being at a competitive disadvantage.[22]

3.2.2 Robotic Feeding

An automation option for dairy producers is an electric automated feed pusher. When cows feed, they push their food away from their stalls, requiring labor to push the feed back toward the cows for proper nutrition to take place. Rather than using human labor and a diesel tractor to push the feed toward the animals, producers can invest in an automated feed pusher robot. These systems are commercially available, and one system can run, recharge, and continue pushing feed 24/7. The cows benefit from not being disturbed by a loud diesel engine and have equal access to nutritional resources, increasing their milk productivity. Although the initial capital cost is high, technology is advancing at a rapid rate, and the cost will continue to decrease over time (Table 6). These capital costs do not incorporate the non-energy

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[20] Tranel, L., *Economics of Robot Milking Systems*, 2017, https://www.usda.gov/oce/forum/past_speeches/2017/2017_Speeches/Larry_Tranel.pdf.

[21] Electric Power Research Institute, *Robotic Milking System*, 2016b https://www.epri.com/#/pages/product/3002008500/?lang=en-US.

[22] Tranel, *Economics of Robot Milking Systems.*

benefits of cow well-being, decreased stress on producers, and increased milk production due to proper nutrition. If used on a dairy operation with self-generated electricity, the tradeoff becomes more appealing because electricity is already being generated on-site and may be provided at a minimal cost.[23]

Table 6. Cost Comparison of Electric Feed Pusher vs. Diesel Feed Pusher

	Electric Feed Pusher	Diesel Feed Pusher
Life Expectancy	15 years	15 years
Initial Cost	$25,000	$1,300**
Annual Energy Cost*	$72 at $0.06/kWh	$144 at $6/MMBtu
Annual Maintenance Cost	$85	$26***
Total Lifetime Cost	$27,355	$3,850
Annual Average Cost	$1,824	$257

**Fuel prices are national averages based on price data from the US Energy Information Administration, http://www.eia.gov/. An electric feed pusher consumes 1,200 kWh annually while the alternative consumes 24 MMBtu annually.*

***Initial cost is only for the feed pusher attachment.*

****Prorated maintenance cost assuming 10% of the equipment's maintenance can be attributed to feed pushing.*

Source: Electric Power Research Institute (2016a), *Electric Feed Pusher*

3.3 Specialty Agriculture

Automation may have the most to offer immediately to specialty agriculture operations. Automated systems for weeding exist for the small greenhouse space but are being scaled up to be available for field crops, as well. Additionally, fully integrated smart greenhouses with automated moisture, nutritional, and lighting control are a reality as more companies enter the space to create solutions for agricultural labor shortages while increasing resource efficiency.

3.3.1 Robot Weeding

Self-driving and artificial intelligence robotics represent both an autonomous solution to weed removal and a growing market. This technology is still in the early stages but is developing quickly, with multiple manufacturers beginning to advertise commercially available robots for the near future. The mechanical removal of the weed from the soil is one form of autonomous weed removal robot. This would be particularly useful for organic farm operations or smaller scale specialty agriculture where mechanical removal is feasible; however, companies are developing large-scale mechanical weed removal systems applicable for field crops.

A closer to market-ready solution uses weed detection and precision herbicide application to kill weeds, rather than a mechanical removal. This solution is being advertised to large field crop producers. The model robot also runs on solar power and claims to run for up to 12 hours, using 90% less herbicide than field spraying. Both the mechanical and chemical options of autonomous weed removal have an unknown initial capital cost as they are either still in the R&D phase or trial manufacturing phase. Neither option is actively commercially distributed, except for on a small scale for specialty agriculture. However, with labor shortages continuing to be a stress on the agricultural system, even a large capital investment in an automated robot weeding system could have a quick payback period due to reduced labor costs and a reduced need for chemical inputs.

[23] Electric Power Research Institute, *Electric Feed Pusher*, 2016a, https://www.epri.com/#/pages/product/000000003002008501/?lang=en-US.

3.3.2 Smart Greenhouses

Big physical spaces represent one of the barriers to automated irrigation with field crops. An Internet of Things system would have to be created with soil sensors and irrigation pumps to cover large distances. The physical space barrier does not exist with most greenhouses. Smart greenhouse technology exists and is on the market, whether based on a hydroponic, aeroponic, or soil-based system. These technologies provide automated lighting systems, automated moisture, and nutrient monitoring and pumping, and automated climate control, and companies are even close to commercially available automated harvesting equipment. Greenhouses and hydroponics can produce higher yields than traditional agricultural means with some species of fruits and vegetables.[24] The potential yield per unit of space is increased even more with a vertical farming model that could solve potential future issues with declining arable land and producing food for a growing population. Nutrients can be monitored and adjusted to maximize yields and taste while reducing input and labor costs. There is also the added benefit of being able to grow in a logistically advantageous location close to population centers, minimizing transportation costs and increasing profits. The current adoption rate of smart greenhouse technology in the U.S. is unknown, but the global market for this emergent technology is expected to grow at a compound annual growth rate of 12% out to 2023 with a value of over $2 billion.[25]

Greenhouse technologies can range from the hundreds to the thousands of dollars, so if a producer wishes to automate processes, initial capital investments can vary widely based on the equipment they already own and the retrofitting possibilities. Greenhouse producers should seek out experienced technology providers, consult with industry experts, and discuss any potential changes in load size or shape that may occur as a result of automation with their energy providers.

[24] Treftz, C. and Omaye, S., 2015, *Comparison Between Hydroponic and Soil Systems for Growing Strawberries in a Greenhouse,* https://naes.agnt.unr.edu/PMS/Pubs/309_2017_03.pdf.

[25] Markets and Markets, *Smart Greenhouse Market*, 2018, https://www.marketsandmarkets.com/Market-Reports/smart-greenhouse-market-63166169.html.