



# Electrified Agriculture: Best Practice Guide for Utilities

**Prepared for:**

**National Electrical Manufacturers Association**



***Submitted by:***

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## TABLE OF CONTENTS

<b>Acknowledgements.....</b>	<b>ii</b>
<b>Definitions.....</b>	<b>ii</b>
<b>Introduction .....</b>	<b>1</b>
<b>1. Overview of the Electrification of Agriculture.....</b>	<b>2</b>
<b>2. Best Practices in Demand Response .....</b>	<b>4</b>
2.1 Demand Response in Agriculture .....	4
2.2 Demand Response Programs and Technologies .....	6
2.3 The Future of Demand Response in Agriculture.....	8
2.3.1 Lack of Digitization in Agriculture .....	9
<b>3. Best Practices in Energy Storage.....</b>	<b>10</b>
3.1 Water Storage .....	11
3.2 Battery Storage .....	12
<b>4. Best Practices in Distributed Generation.....</b>	<b>13</b>
4.1 Technologies Available for Distributed Generation.....	13
4.2 Benefits of On-Farm Distributed Generation.....	15
4.3 Challenges of On-Farm Distributed Generation.....	16
4.4 The Future of Distributed Generation in Agriculture .....	17
<b>5. Forecasted Electricity Growth in the Agriculture Sector.....</b>	<b>18</b>

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## DEFINITIONS

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

**Agriculture:** The production of crops or livestock for food or products.

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

## INTRODUCTION

This document highlights best practices and considerations for utilities as they prepare for the increase in electricity use in the agriculture sector. The document showcases technologies and processes that will enable that transition and facilitate engagement by utility members. For insight into technologies and considerations for farmers looking to electrify, please consult the NEMA *Best Practice Guide for Farmers*.

The guide is a resource that utilities can use to start conversations between stakeholders and interested parties working toward key paths to an electrified agricultural sector. Best efforts were put forth to create an accurate and useful document, which discusses the general technical details of electrification in agriculture. The pursuit of programs or policies should be made with qualified professionals experienced in these fields. Additionally, this guide presents an unbiased approach to the different methods of electrification.

This document has five sections. It first presents an overview, including a high-level discussion of the electrification opportunities and challenges in agriculture. Second, the document illustrates three topics, 1) demand response (DR), 2) energy storage, and 3) distributed generation, and their ability to aid utilities coping with increased electricity demand and their adoption challenges, solutions. Finally, the impacts section gives an overview of the historical trend in electricity growth in agriculture and the increase in electricity demand that utilities can expect in the future.

The key takeaways from this report are the following:

- The main use of electricity in non-dairy farm agricultural operations is irrigation. Utilities that seek to optimize electricity loads using technologies such as DR should focus first on irrigation as end use.
- Farmers are increasingly becoming energy producers to supplement income, aided by new methods such as agrivoltaics, or growing crops under solar panels. Properly managed, this could prove beneficial for utilities unprepared to supply the additional power demand resulting from electrification.
- The technologies in this report are not standalone solutions. Farmers can produce and store electricity independently of a utility provider, but the greatest energy resilience and electricity cost savings will come from combining these technologies with utility-supplied services such as demand response.
- Agriculture makes up a small portion of the country's total energy use and is not broken out in most databases. Instead, it is grouped into the industrial sector. As industrial uses of electricity are highly varied, any forecasts for agricultural consumption based on industry forecasts will be minimally informative.

## 1. OVERVIEW OF THE ELECTRIFICATION OF AGRICULTURE

Electrification is a trend occurring in almost every sector of the economy. Spurred by technology such as electric heat pumps and electric vehicles, and the cost savings potential they encompass, electrification could increase electricity consumption in the country by almost 40 percent by 2050.<sup>1</sup>

Agriculture is no exception. Irrigation, in particular, has become increasingly electrified, as, according to the Farm and Ranch Irrigation Survey, in 2013, 85 percent of irrigation pumps were electric and only 13 percent of pumps are powered by diesel.<sup>2</sup> The recent growth of indoor agriculture, or vertical farming, is also increasing electricity usage on farms. Indoor agriculture uses artificial lighting to supplement or even replace natural light, and as the demand for food increases, innovative indoor agriculture solutions hold many benefits including reduced water usage, increased ability for urban farming, and reduced food transport distances.<sup>3</sup> This industry is projected to grow by 24 percent into a \$3 billion industry in the US by 2024 and is an opportunity for utilities to offer new products and services to farmers that previously relied on traditional outdoor growing practices.<sup>4</sup> Other equipment, discussed in the *Guide for Farmers*, is also predicted to add to a farm's demand for electricity as agriculture moves away from fossil fuels.

For utilities, increased agricultural electrification, especially when coupled with more distributed renewable generation, could have significant implications. This is particularly true in the Midwest and West, where farmland irrigation can amount to up to 30 percent of a utility's load, and in states such as Texas, Nebraska, and Kansas, where agricultural customers represent the majority of utilities' industrial customers.<sup>5</sup>

Agricultural electrification can have different effects for utilities depending on whether a farm sources its electricity from the grid or produces it onsite. If the farm gets its electricity from the grid, electrification represents an opportunity for utilities to boost sales. While currently only about 18 percent of the fuel consumed on a farm is electricity, continued conversions of equipment fossil fuel-powered to electricity are estimated to generate \$4.4-\$5.4 billion in new annual revenue for rural electrical cooperatives.<sup>6</sup> Future technology that includes advanced sensors, monitoring, and automation will only add value to electrified farm equipment. As methods such as precision agriculture become more prevalent, these advancements could even necessitate farmers convert from old fossil fuel equipment to stay competitive.

For farms that produce electricity onsite (distributed generation) in the form of solar, wind, or biogas, the opposite is true. As farms become producers of renewable energy, electrification of agricultural operations does not necessarily result in increased demand as farms instead rely more on the power produced on their land and less on traditional utility-distributed resources.<sup>7</sup> In some cases, farms are becoming net energy generators, supplying more energy to the grid than they take from it.<sup>8</sup> This is due in part to the suitability of agricultural land for distributed energy—for example, over half of the states with significant irrigation, and therefore farmland, are also states with good wind resources.<sup>9</sup> Additionally,

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<sup>1</sup> <https://www.greentechmedia.com/articles/read/widespread-electrification-could-increase-u-s-electricity-consumption#qs.5w6gti>

<sup>2</sup> [http://eta-publications.lbl.gov/sites/default/files/agriculturedr\\_aghajanzadeh.pdf](http://eta-publications.lbl.gov/sites/default/files/agriculturedr_aghajanzadeh.pdf)

<sup>3</sup> <http://mydocs.epri.com/docs/PublicMeetingMaterials/ee/000000003002011536.pdf>

<sup>4</sup> <https://www.prnewswire.com/news-releases/the-us-vertical-farming-market-is-projected-to-reach-values-of-around-3-billion-by-2024-300782225.html>

<sup>5</sup> <https://www.eia.gov/todayinenergy/detail.php?id=16231>

<sup>6</sup> Farm Beneficial Electrification: Opportunities and Strategies for Rural Electric Cooperatives, October 2018

<sup>7</sup> [http://eta-publications.lbl.gov/sites/default/files/agriculturedr\\_aghajanzadeh.pdf](http://eta-publications.lbl.gov/sites/default/files/agriculturedr_aghajanzadeh.pdf)

<sup>8</sup> [http://eta-publications.lbl.gov/sites/default/files/agriculturedr\\_aghajanzadeh.pdf](http://eta-publications.lbl.gov/sites/default/files/agriculturedr_aghajanzadeh.pdf)

<sup>9</sup> <https://www.nrel.gov/docs/fy10osti/47971.pdf>

electricity prices in rural and agricultural communities are often some of the most expensive, making cheap wind and solar an economically favorable alternative.

Managed correctly, however, excess distributed generation on farms can prove beneficial for utilities serving agricultural customers. As farms electrify, utilities must be prepared to supply the extra power demanded from the electrified machines. Due to past investments in old, expensive coal plants, many rural co-ops that supply power to farms may struggle to keep up with the increased demand. Forced to put resources into paying off the debt from these investments instead of building new capacity, rural utilities could benefit from the increased power farms will supply to the grid without incurring the capital cost of building out new capacity.<sup>10</sup> The challenge for the utility is striking a balance with agricultural customers between the increased demands of electrification and the increased supply from distributed energy resources.

Whether a farm gets its electricity from the grid or produces it onsite, electrification is an opportunity for utilities and the extended agriculture community to develop stronger communication and relationships. As farms move toward becoming wind and solar farms in addition to growing crops or raising livestock, this relationship will prove critical to maintaining a stable, connected, resilient electric grid. Utilities as energy experts have the opportunity to take on the role of the educator to explain how a stable and resilient grid will depend on the symbiosis of beneficial electrification and distributed energy generation. Utilities must also plan to educate agricultural customers on the current technologies, programs, and market mechanisms that will make that system function.

Depending on the generation mix of the utility, electrifying the agricultural industry will also help state and local governments reach greenhouse gas (GHG) emission reduction goals. The total GHG emissions in 2017 for the US agricultural sector was 582 million metric tons. Of this, fuel use still accounted for 8 percent, or 46 million metric tons, equivalent to burning over five billion gallons of gasoline.

Onsite distributed renewable energy generation on farms also contributes to the greening of the grid, with a study out of Oregon State University finding that agricultural land was among some of the best for solar panel installations. The same study found that installing solar panels on just 1 percent of the land used for farming globally would result in enough energy to supply global energy demand.<sup>11</sup>

These trends may motivate regulatory change as farms become more dominant energy producers. Regulation on distributed energy sources—including net metering laws, tariffs, interconnection regulation, land use taxes, and licensing—vary by state and even by utility. As renewable energy generation increases on farms, utilities and state regulators must take a critical look at how current regulation is either helping or harming the electricity grid. Policies that disincentivize grid connection may result in the loss of agricultural customers as they become self-sufficient power generators. Policies that promote too much renewable power being sold back to the grid will cause utilities to scramble to manage intermittency and over- or under-generation. Finally, policy relating to DR and energy storage should be assessed, and if necessary, updated to encourage the use of these strategies to support grid resilience.

<sup>10</sup> <https://www.cleancooperative.com/news/rural-america-could-power-a-renewable-economy-but-first-we-need-to-solve-coal-debt>

<sup>11</sup> [https://today.oregonstate.edu/news/installing-solar-panels-agricultural-lands-maximizes-their-efficiency-new-study-shows#targetText=It%20turns%20out%20that%208%2C000,harvest%20solar%20energy%20on%20Earth."&targetText=For%20thei%20study%2C%20OSU%20researchers,lands%20owned%20by%20Oregon%20State.](https://today.oregonstate.edu/news/installing-solar-panels-agricultural-lands-maximizes-their-efficiency-new-study-shows#targetText=It%20turns%20out%20that%208%2C000,harvest%20solar%20energy%20on%20Earth.)

## 2. BEST PRACTICES IN DEMAND RESPONSE

As utilities plan for future grid needs, two factors must be considered: increased electricity demand from customers and increased electricity supply from intermittent, distributed renewable energy sources. While distributed energy may help offset increased demand, the variable nature of renewable resources can exacerbate issues of misaligned peak demand and peak supply. As more renewables, distributed generation, and technology (such as energy storage connected to the grid) are implemented, greater flexibility and control over when energy is consumed will be critical to maintaining a stable, cost-effective system.

Utilities can use DR, changing a customer's usage patterns via price structuring or incentives as a strategy to provide such control over energy consumption. Through pricing, opt-in programs, events, and behavioral change, DR allows utilities to shift demand away from periods of high power draw and toward periods of high power supply. For rural utilities in agriculture-heavy states, DR will be a valuable tool to help handle a changing energy landscape as farms turn to electricity and renewables to meet their needs.

### 2.1 Demand Response in Agriculture

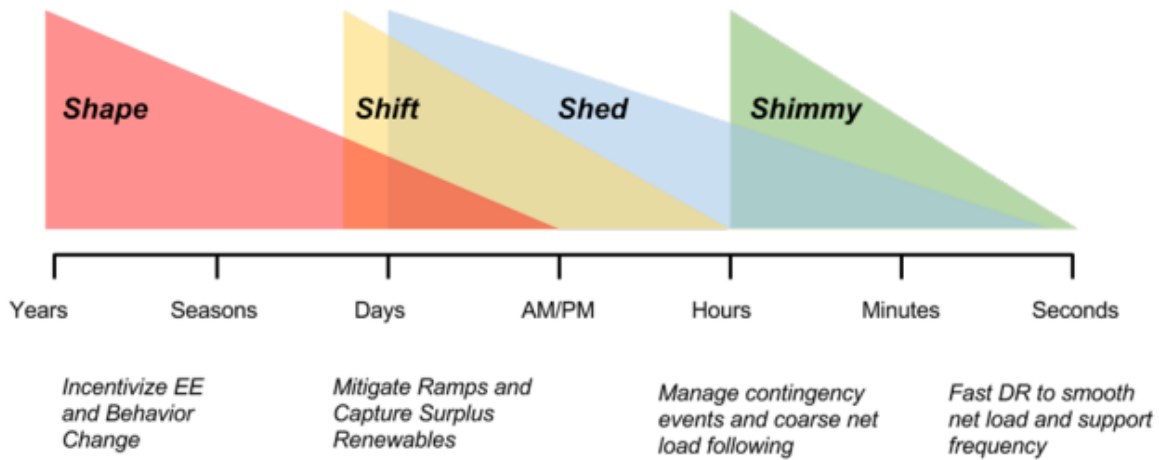
DR can change load shapes in four ways (see Figure 1):<sup>12</sup>

1. **Shifting** seeks to change energy consumption patterns away from periods of high demand to periods when supply is high or at an excess. Shifting most often is accomplished by finding alternative ways to use and store energy when supply is high, such as using energy storage or encouraging EV charging during certain times of the day.
2. **Shaping** refers to a long-term, persistent shifting or shedding behavior. It requires the longest timescale and modifies customer usage using pricing or behavioral strategies. Time-of-use (TOU) rates and peak pricing are examples of DR shaping.
3. **Shedding** is deployed during emergency or contingency events to shut offloads and provide capacity to the system on a one-off basis. Dispatch and response times vary depending on the event and can include curtailing lighting, cooling, or other interruptible loads.
4. **Shimmying** functions at the hour to second timescales and is used to smooth loads and manage short-term fluctuations. It responds in real-time and looks to optimize all system components to decrease the need to ramp up or down.

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<sup>12</sup> Navigant Research, *Demand Response for Renewables Integration*, 2017.

**Figure 1. Types of DR Services Presented Based on Time for Dispatch and/or Response**



Source: Lawrence Berkeley National Laboratory, *Agricultural Demand Response for Decarbonizing the Electricity Grid*, 2019.

To be effective, DR strategies must align with the electric loads of a customer. On a farm, this will typically be irrigation, the largest end-use for electricity for most agricultural customers.<sup>13</sup> In these systems, electricity is used to pump, divert, and pressurize water throughout the day. The systems are composed of several components including pumps (85 percent of which are now electric<sup>14</sup>), variable frequency drives (VFDs), water storage, and, in some cases, onsite distributed power generation. Each component represents an opportunity for DR based on the level of automation, time to respond to events, and the ability to vary demand. Table 1 demonstrates the most common components and their corresponding characteristics.

<sup>13</sup> Lawrence Berkeley National Laboratory, *Agricultural Demand Response for Decarbonizing the Electricity Grid*, 2019, [http://eta-publications.lbl.gov/sites/default/files/agriculturedr\\_aghajanzadeh.pdf](http://eta-publications.lbl.gov/sites/default/files/agriculturedr_aghajanzadeh.pdf).

<sup>14</sup> Lawrence Berkeley National Laboratory, *Agricultural Demand Response for Decarbonizing the Electricity Grid*



Table 1. Agricultural Irrigation System Components and Their DR Considerations<sup>15</sup>

Equipment	Automation	Response Time	Demand Flexibility [%]	Operational Limits
Groundwater Pump (GW)	Manual	Minutes-Hours	± 100%	Requires advance notice, planning, and reallocation of labor
Surface Water Pump (SW)	Semi-Automated	Seconds-Minutes	± 100%	Limited by water allocations and surface water deliveries
Booster Pump	Semi-Automated	Seconds	± 100%	Limited by irrigation schedules and irrigation system type
Groundwater Pump + VFD	Automated	Minutes	Variable	VFDs are not suited for high static head systems (e.g. GW pumping)
Surface Water Pump + VFD	Automated	Seconds	Variable	Limited by water allocations and surface water deliveries
Booster Pump + VFD	Automated	Seconds	Variable	Limited by irrigation schedules and irrigation system type
Water Storage	Semi-Automated	Hours-Day	Variable	Building surface storage reservoirs are costly and currently not common on farms without pressurized irrigation
On-Site Generation	Automated	Seconds	Variable	Limits imposed by the local utility (e.g. Net metering)

Source: Lawrence Berkeley National Laboratory, *Agricultural Demand Response for Decarbonizing the Electricity Grid*

±100% indicates systems that are binary and can only be on or off.

Based on the characteristics and restraints detailed in Table 1, the most promising opportunity for DR lies in water storage for irrigation coupled with groundwater pumps, and in smaller booster pumps outfitted with VFDs. DR strategies that focus on shifting loads are the best match for agricultural customers as these components' automation, short- to medium-term response, and variable demand flexibility mean that irrigation systems can respond to a DR event by either increasing pumping to water storage during times of high energy supply or by using VFDs to decrease the load from pumps while still maintaining system operating requirements.

Another promising opportunity for DR strategies is indoor or vertical farming. These operations, which grow crops inside in a highly optimized environment, can be exceedingly automated, with everything from lighting, temperature, and watering schedules run via programmed controls and sensors. The advanced technology on these electrical loads and the ability to shift growing schedules independently of when the sun is shining makes indoor agriculture operations particularly fitting candidates for utility DR programs looking to shift loads to off-peak periods.

## 2.2 Demand Response Programs and Technologies

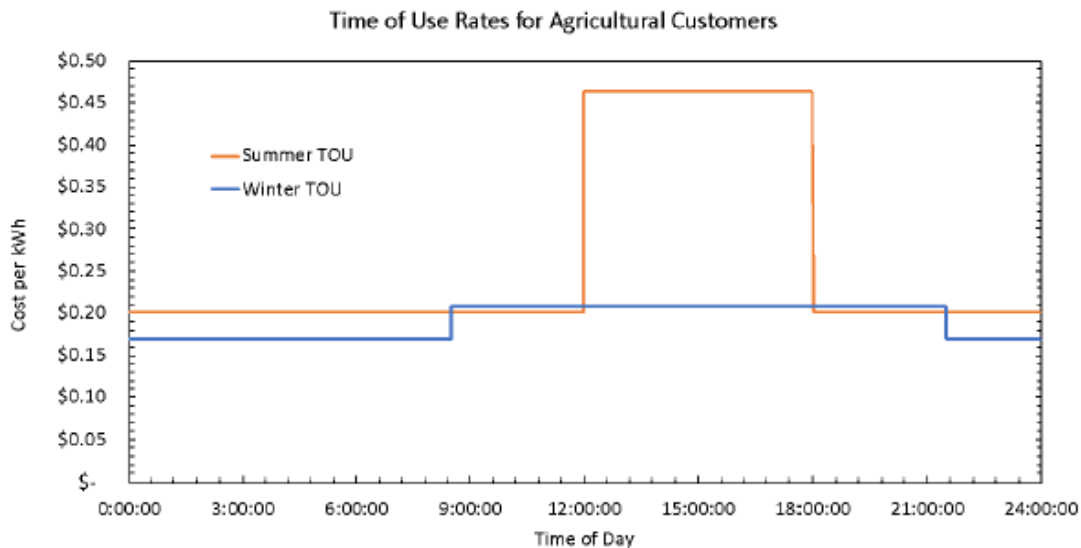
To be operational, DR requires two components: incentives to motivate a customer to change their energy usage and technology that allows users to enact those load variations.

Programs to incentivize DR applicable to agricultural customers include TOU, distribution DR, and event-based DR. Participating in TOU rate plans creates the most permanent form of load shifting and is

<sup>15</sup> Internal expertise suggests that Groundwater Pump + VFD systems are in fact operational, with a significant number of groundwater pumps successfully powered by VFDs. DR is instead limited by irrigation schedules and irrigation system type.

currently the most accepted by agricultural customers.<sup>16</sup> TOU programs can be achieved with the technology currently installed on most farms and are relatively simple to understand.<sup>17</sup> For utilities, it is historically the most cost-effective way to incentivize behavior change.<sup>18</sup> However, there is no way to guarantee that a participant adheres to the TOU schedule. Additionally, the need to irrigate during certain times of the day, especially during peak growing season, may trump TOU price incentives.

Figure 2. Time-of-Use Rates for PG&E Agricultural Customers



Source: Arian Aghajanzadeh et al., *Water-Energy Considerations in California’s Agricultural Sector and Opportunities to Provide Flexibility to California’s Grid*

Real-time DR (or AutoDR) programs send DR event signals based on the fluctuating supply and demand to the grid. These programs allow for greater flexibility in the system, and utilities can shift loads to optimal times during the day on a minute or even second timescale. However, there are many barriers to this type of DR program. AutoDR requires that irrigation systems have automated controls, are able to receive DR signals, and asks farmers to give up on traditional irrigation schedules tuned to crop needs in favor of dynamic pricing catering to the energy system. While providing greater benefits to utilities, this would require a larger effort and greater financial incentives to achieve acceptance and adoption.

For agricultural customers, automatic controls installed on the pumps in an irrigation system is the main technology that enables DR. These controls automatically respond to signals from the utility or third-party operator that notify of a DR event. These events can be consistent TOU pricing schedules or variable one-time DR events. While automatic controls require less daily interaction from the customer, they come with several challenges. First, most pumps in operation are manual, which necessitates turning them on and off by hand.<sup>19</sup> The cost and time to install automatic controls can be enough of a barrier to dissuade a customer from participating in DR. Second, automatic controls work by either receiving signal on a demand response automation server (DRAS) directly on the control or by communicating with a remote DRAS. This necessitates the ability to connect via Wi-Fi, telecommunication, or satellite services to

<sup>16</sup> US Department of Energy Office of Scientific and Technical Information, *Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study*, 2013, <https://www.osti.gov/servlets/purl/1172125>.

<sup>17</sup> Arian Aghajanzadeh, Michael D. Sohn, Michael A. Berger, *Water-Energy Considerations in California’s Agricultural Sector and Opportunities to Provide Flexibility to California’s Grid*, Lawrence Berkeley National Laboratory, 2019.

<sup>18</sup> Arian Aghajanzadeh et al, *Water-Energy Considerations in California’s Agricultural Sector and Opportunities to Provide Flexibility to California’s Grid*.

<sup>19</sup> US Department of Energy Office of Scientific and Technical Information, *Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study*, 2013, <https://www.osti.gov/servlets/purl/1172125>.

function. In rural agricultural areas with limited connectivity, such communication may entail additional technological costs and upgrades.

Manual controls can also be used and are found on most pumps today. This bypasses the need for the farmer to purchase, install, and learn to operate new technology while still allowing them to participate in DR programs. However, because pumps must be turned on and off by hand, using manual controls for DR can be time-consuming. The farmer must either program a pump timer to align with the DR program requirements or access each pump individually to turn them off for one-off DR events.

Finally, VFDs can enhance systems to provide more fine-tuned DR capabilities. They enable load reductions instead of simply load termination and allow irrigation systems to continue to function while responding to DR events. Flood irrigation can particularly benefit from installed VFDs as, unlike other irrigation systems, it does not require specific pressures to operate.<sup>20</sup> Like automatic controls, however, VFDs are not common on most irrigation systems, and little is known about how growers may respond to encouraged adoption.

## 2.3 The Future of Demand Response in Agriculture

Agriculture represents a large potential for increased DR capacity, particularly for states with substantial agricultural output. In California, for example, were irrigation shifted to operate during midday instead of from 4 p.m. to 7 p.m., it would almost entirely account for the additional 1.3 GW of energy storage mandated by 2020.

This can be done with minimal capital expenditure. DR is cheap compared to other grid management options such as new generation development or battery storage, and it is estimated that DR-enabled irrigation could result in up to 75 percent cost savings when used in place of other methods to meet rising demand.<sup>21</sup>

Finally, because DR relies on customer participation, it can provide a gateway to a more engaged and positive relationship between utilities and farmers. Insightfully designed and intelligently implemented DR programs, particularly when combined with on-farm power generation, give farmers better insight into their energy use and allow them to maximize their use of the cheapest available electricity. Enhanced service and lower energy costs may be one way to foster a more agreeable view of the utility and improve customer relations.

Despite these benefits, past attempts to disseminate DR programs have, for the most part, failed. In the early 2000s, the company M2M Communications brought irrigation-specific wireless and satellite-based DR technology to the market.<sup>22</sup> Contracting with utilities, it outfitted irrigation systems with remote control capabilities to help shed power during peak periods by allowing farmers to turn off or reduce irrigation power draws during those times. However, a decade later, only 4 percent of agricultural customers in California are participating in a DR program.<sup>23</sup>

<sup>20</sup> US Department of Energy Office of Scientific and Technical Information, *Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study*, 2013, <https://www.osti.gov/servlets/purl/1172125>.

<sup>21</sup> Lawrence Berkeley National Laboratory, *2025 California Demand Response Potential Study – Charting California’s Demand Response Future: Final Report on Phase 2 Results*, 2017, <http://eta-publications.lbl.gov/sites/default/files/lbnl-2001113.pdf>.

<sup>22</sup> Jeff St. John, “M2M Brings Demand Response to Farmers,” *Greentech Media*, 2009, <https://www.greentechmedia.com/articles/read/m2m-brings-demand-response-to-farmers#gs.40nr8s>.

<sup>23</sup> Demand Response Research Center, *2025 California Demand Response Potential Study - Charting California’s Demand Response Future: Final Report On Phase 2 Results*, 2017, <https://drrc.lbl.gov/publications/2025-california-demand-response>

### 2.3.1 Lack of Digitization in Agriculture

A lack of digitization in agriculture, one of the least digitized industries in the US, presents the first barrier to more widespread adoption.<sup>24</sup> Many irrigation systems are partially or fully manual, and rural operations often do not have immediate access to the Wi-Fi and communication networks needed to send and receive signals. While these technologies exist, they must be further enhanced to truly provide a seamless DR experience, both for the customer and the utility. Most DR tech operates on too large of a time scale (hours, days, or weeks) to be useful in daily load shifting. Additional developments to DR technology, such as integrating real-time pricing and transactive energy will make them more compatible with complex grid fluctuations.<sup>25</sup>

Stakeholder engagement will prove critical to overcoming these technological challenges. First, DR technology must be installed for it to be beneficial, and agricultural customers must be convinced of the value of participating in DR programs. In return, DR programs should provide the greatest possible grid management benefits to a utility by intelligently taking advantage of the characteristics of different irrigation system components. Conversations with stakeholders will help illuminate ways current DR programs provide these benefits and where they can be improved to add even greater value.

Second, participating in DR must be easy. Current programs are typically complex to enroll and participate in, and technology can be complicated to install and operate. Farmers often look to external consultants for guidance on a process outside of their own skillset, making participation an even more burdensome experience. Research, including interviews with potential agricultural DR customers, should be conducted before finalizing or attempting to enroll customers in a program that may be ill-fit to the needs of a farming operation.

Finally, stakeholders in the DR landscape—utilities, technology and software developers, regulators, and customers—must come up with new market mechanisms that satisfy both the needs of an agricultural operation and grid management concerns. Traditional DR programs aimed at residential or even industrial customers are not tailored to meet the needs of agricultural operations. Co-benefits, such as DR's ability to maximize the impact of distributed generation resources, need to be leveraged when developing DR programs and technology. Identifying other agricultural technologies (such as soil moisture sensors) and understanding how they might enhance or even detract from DR should also be considered in program design.<sup>26</sup>

There is great potential for DR in agriculture to benefit both farmers and utilities, but it will only be realized once the barriers to digitization and a lack of tailored market mechanisms are overcome.

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<sup>24</sup> <https://www.greenbiz.com/article/why-silicon-valley-should-take-ag-tech-more-seriously>.

<sup>25</sup> Lawrence Berkeley National Laboratory, *Agricultural Demand Response for Decarbonizing the Electricity Grid, 2019*, [http://eta-publications.lbl.gov/sites/default/files/agriculturedr\\_aghajanzadeh.pdf](http://eta-publications.lbl.gov/sites/default/files/agriculturedr_aghajanzadeh.pdf).

<sup>26</sup> Arian Aghajanzadeh, Michael D. Sohn, Michael A. Berger, *Water-Energy Considerations in California's Agricultural Sector and Opportunities to Provide Flexibility to California's Grid*, Lawrence Berkeley National Laboratory, 2019.

### 3. BEST PRACTICES IN ENERGY STORAGE

Energy storage methods and technologies have the potential to reduce costs and improve grid reliability and stability for both utilities and agricultural customers. Sector-specific techniques such as water pumping and storage for irrigation provide an important DR tool that can help shift agricultural electricity demand to off-peak hours.<sup>27</sup> Storage technologies and systems such as batteries and pumped-storage hydropower allow both customers and utilities to reduce peak demand costs and access energy reserves in case of generation disruptions.

Technological advancements in energy storage systems are also supporting the integration of renewable energy into the electric grid and increasing electric reliability and resiliency for utility customers. Energy storage systems include mechanical (e.g., pumped-storage hydropower), thermal (e.g., molten salt), chemical (e.g., hydrogen), electro-chemical (e.g., lithium-ion batteries, lead-acid batteries), and electrical (e.g., supercapacitors) systems.<sup>28</sup> Table 2 provides a summary of energy storage technologies with large storage capacities of at least 20 MW, highlighting the strengths and weaknesses of individual technologies from the perspective of maximum storage, discharge time, lifetime, energy density, and efficiency.

**Table 2. Characteristics of Selected Energy Storage Systems<sup>29</sup>**

Storage Technology	Max Power Rating (MW)	Typical Discharge Time	Lifetime or Max Cycles	Energy Density (watt-hour per liter)	Efficiency
Pumped hydro	3,000	4 hours – 16 hours	30–60 years	0.2–2	70%–85%
Compressed air	1,000	2 hours – 30 hours	20–40 years	2–6	40%–70%
Molten salt (thermal)	150	hours	30 years	70–210	80%–90%
Li-ion battery	100	1 minute – 8 hours	1,000–10,000	200–400	85%–95%
Lead-acid battery	100	1 minute – 8 hours	6–40 years	50–80	80%–90%
Flow battery	100	hours	12,000–14,000	20–70	60%–85%
Hydrogen	100	mins – week	5–30 years	600 (at 200bar)	25%–45%
Flywheel	20	secs – mins	20,000–100,000	20–80	70%–95%

Energy storage technologies offer considerable benefits to both utilities and electric consumers. However, the storage capabilities and costs associated with individual technology types are key considerations that will influence the uptake of certain energy storage technologies among agricultural customers.

<sup>27</sup> Lawrence Berkeley National Laboratory, *Agricultural Demand Response for Decarbonizing the Electricity Grid*, 2019, [http://eta-publications.lbl.gov/sites/default/files/agriculturedr\\_aghajanzadeh.pdf](http://eta-publications.lbl.gov/sites/default/files/agriculturedr_aghajanzadeh.pdf).

<sup>28</sup> World Energy Council *E-Storage: Shifting from Cost to Value 2016*, 2016, <https://www.worldenergy.org/publications/entry/e-storage-shifting-from-cost-to-value-2016>.

<sup>29</sup> Environmental and Energy Study Institute, “Fact Sheet: Energy Storage,” 2019, <https://www.eesi.org/papers/view/energy-storage-2019>.

Energy storage is gaining traction at record rates, with global annual storage deployment nearly doubling from 1.7 GW in 2017 to 3.1 GW in 2018.<sup>30</sup> In the US, battery storage is a primary driver of overall energy storage adoption, with battery storage capacity quadrupling from 241 MW in 2013 to 963 MW in 2017.<sup>31</sup> Electric companies and utilities are fueling the rapid expansion and adoption of energy storage systems, with electric companies owning, procuring, or utilizing 98 percent of all energy storage available in the US.<sup>32</sup>

Energy storage systems provide a slew of services to the power grid, including increased electric supply capacity, power reliability, demand charge management, transmission congestion relief, and voltage support.<sup>33</sup> These grid-level benefits, along with increased opportunities for onsite generation and distributed energy resources, make energy storage systems an attractive option for utilities and farmers seeking long-term energy savings and increased electric reliability.

This section highlights the best available energy storage options for use in the agricultural sector, describing the benefits and limitations of each option based on the needs and constraints of agricultural users.

## 3.1 Water Storage

Water storage is an extremely simple energy storage method with the potential for significant cost savings associated with agricultural electricity use. In-soil water storage can be accomplished by either flooding fields to recharge groundwater aquifers or by changing the makeup of the soil to increase its ability to hold more moisture.<sup>34</sup> Aboveground storage can be done by pumping water into on-farm water reservoirs (e.g., ponds) or containers (e.g., water tanks or cisterns).



Source: [Casey Schackow on Unsplash](#)

For many farmers, water pumping for irrigation purposes is a primary driver of electricity costs, with the vast majority of farmers relying on electric pumps versus diesel pumps to convey water.<sup>35</sup> In California, water pumping accounts for 70 percent of agricultural energy use.<sup>36</sup> By pumping water during off-peak hours and storing water in soil or aboveground, farmers can avoid or reduce peak demand costs and use the stored water in a more economical manner.<sup>37</sup> This method presents significant energy cost

<sup>30</sup> Luis Munuera, *Energy Storage: Tracking Clean Energy Progress*, International Energy Agency, 2019, <https://www.iea.org/tcep/energyintegration/energystorage/>.

<sup>31</sup> Edison Electric Institute, *Harnessing the Potential of Energy Storage*, 2019, [https://www.eei.org/issuesandpolicy/Energy%20Storage/Harnessing\\_Energy\\_Storage\\_Factsheet.pdf](https://www.eei.org/issuesandpolicy/Energy%20Storage/Harnessing_Energy_Storage_Factsheet.pdf).

<sup>32</sup> Edison Electric Institute, *Harnessing the Potential of Energy Storage*.

<sup>33</sup> International Renewable Energy Agency, *Renewable Energy Prospects: United States of America, REmap 2030 Analysis*, 2015, [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA\\_REmap\\_UAE\\_report\\_2015.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_REmap_UAE_report_2015.pdf).

<sup>34</sup> Lawrence Berkeley National Laboratory, *Agricultural Demand Response for Decarbonizing the Electricity Grid*, 2019, [http://eta-publications.lbl.gov/sites/default/files/agriculturedr\\_aghajanzadeh.pdf](http://eta-publications.lbl.gov/sites/default/files/agriculturedr_aghajanzadeh.pdf).

<sup>35</sup> US Department of Agriculture, *2013 Farm and Ranch Irrigation Survey*, 2013, [https://www.nass.usda.gov/Publications/AgCensus/2012/Online\\_Resources/Farm\\_and\\_Ranch\\_Irrigation\\_Survey/](https://www.nass.usda.gov/Publications/AgCensus/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/).

<sup>36</sup> USDA California Climate Hub, "California's Farmers Save on Electric Well Pumps," University of California, Davis, 2016, <https://caclimatehub.ucdavis.edu/2016/06/17/californias-farmers-save-on-electric-well-pumps/>.

<sup>37</sup> Lawrence Berkeley National Laboratory, *Agricultural Demand Response for Decarbonizing the Electricity Grid*

savings for farmers, and increased engagement to drive uptake among farmers could make water storage a useful and inexpensive demand respond tool for utilities.

### 3.2 Battery Storage

Battery costs have dropped rapidly in recent years and battery storage is an increasingly viable option for utilities and customers. Levelized cost of electricity (LCOE) for utility-scale lithium-ion battery storage systems fell from nearly \$800/MWh in 2013 to \$187/MWh in early 2019, representing an approximately 76 percent decrease in LCOE.<sup>38</sup>

Access to inexpensive battery storage technologies would make solar a more attractive option for farmers. The coupling of solar PV systems with battery storage capabilities would allow farmers to store excess solar power, which could then be deployed during peak demand periods or when solar production is low (e.g., during a cloudy or stormy day). From the utility perspective, targeted financial incentives to promote behind-the-meter demand reduction technologies would help reduce the cost barriers associated with battery storage technologies, allowing farmers to participate in the integration of distributed energy resources into the grid. As battery prices continue to fall and state and federal regulatory landscapes become more favorable, the implementation of both behind-the-meter and front-of-the-meter battery storage systems will become more commonplace.

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<sup>38</sup> Veronika Henze, "Battery Power's Latest Plunge in Costs Threatens Coal, Gas," BloombergNEF, 2019, [https://about.bnef.com/blog/battery-powers-latest-plunge-costs-threatens-coal-gas/#\\_ftn1](https://about.bnef.com/blog/battery-powers-latest-plunge-costs-threatens-coal-gas/#_ftn1).

## 4. BEST PRACTICES IN DISTRIBUTED GENERATION

The diversification of energy resources is one of the most prevalent transformations in the energy industry. New technology is expanding generation portfolios beyond the traditional centralized power plant model to include small wind farms, solar gardens, and biogas digesters.

The ability to deploy these technologies alongside current farm operations means farmers have a unique role to play in this transformation. Between 2007 and 2012, the number of farms with onsite electricity production doubled.<sup>39</sup> Today, 2.7 percent of farms produce energy on their land, either to run or enhance their own operation or to sell back to the grid.

### 4.1 Technologies Available for Distributed Generation in Agriculture

Solar is the predominant form of agricultural distributed generation, with solar installed on 82 percent of farms with distributed energy generation.<sup>40</sup> Farms were some of the first businesses to use solar PV in the form of small-scale, off-grid systems supplying only the farm’s energy needs.<sup>41</sup> Most often, off-grid systems generated power to pump water in locations where power lines do not exist and are costly to build. Additional operational applications included building lighting, ventilation, climate control, water heating, and electric fences, among others (Table 3).

Table 3. Farm Applications of Solar Energy

		<b>Fields</b>	<b>Livestock</b>	<b>Other</b>
<b>Water Pumping</b>	PV	wells, ponds, streams, irrigation	wells, ponds, streams	domestic uses
<b>Buildings Needs</b>	PV		security and task lighting, ventilation, feed or product handling equipment, refrigeration	battery charging, task lighting, ventilation fans, AC needs, refrigeration
	SH*		air cooling, air/space heating, water heating	domestic uses of solar heat
<b>Farm and Ranch</b>	PV	feeder/sprayer, irrigation sprinkler controls, security and task lighting,	electric fences, feeder/sprayer	electric fences, invisible fences, battery charging, compressor for fish farming, fans for crop drying, greenhouse heating
	SH*			crop drying, greenhouse heating

\*solar heat

Source: Expanded from NREL, *Electricity When and Where You Need It: From the Sun. Photovoltaics for Farms and Ranches*, 1997

Today, larger grid-connected systems that generate energy to sell back to utilities are also gaining traction. Energy generation as a source of income is increasingly attractive as higher state renewable energy goals and standards, recent declines in agriculture profits, and a better understanding of the interactions between on-farm solar panels and crop production emerge. Considering solar installed for

<sup>39</sup> Lawrence Berkeley National Laboratory, *Agricultural Demand Response for Decarbonizing the Electricity Grid*, 2019, [http://eta-publications.lbl.gov/sites/default/files/agriculturedr\\_aghajanzadeh.pdf](http://eta-publications.lbl.gov/sites/default/files/agriculturedr_aghajanzadeh.pdf).

<sup>40</sup> Lawrence Berkeley National Laboratory, *Agricultural Demand Response for Decarbonizing the Electricity Grid*

<sup>41</sup> US Department of Agriculture, *Solar Energy Use in US Agriculture Overview and Policy Issues*, 2011, [https://www.usda.gov/oce/reports/energy/Web\\_SolarEnergy\\_combined.pdf](https://www.usda.gov/oce/reports/energy/Web_SolarEnergy_combined.pdf).



both on-farm and grid-connected use, solar PV is the most common form of solar energy production, accounting for 90% of solar installations, followed by solar thermal.<sup>42</sup> As of the most recent data available, in 2012, 1.7% of US farms had installed solar panels either for personal or grid-connected use.<sup>43</sup>

First used by farmers from 1870 to 1930 to pump water and generate power, wind is another renewable energy source with roots in agriculture.<sup>44</sup> Today, wind energy is most common in the Midwest and West, where farms are located in areas with higher average wind speeds. Farmers can either produce wind to power their own operations, lease their land to wind developers, or install wind capacity to sell back to the grid.

However, wind energy has more constraints compared to other distributed generation resources. To produce enough energy to sell back to the grid, wind turbines must be located in an area with an average wind speed of at least 10 mph.<sup>45</sup> Wind turbines also need a larger area than other distributed energy, requiring at least half an acre for a large wind turbine.<sup>46</sup> Despite these limitations, wind is the second-most installed type of distributed energy on farms, with as of 2009 17 percent of farms that had installed distributed generation reporting that they had installed wind, representing 0.06 percent of farm operations in the US.<sup>47, 48</sup>

Other innovative distributed generation technologies are available to certain types of agricultural producers. Livestock farms, for example, can use biogas converters to generate renewable onsite electricity. This technology converts the methane produced in the breakdown of livestock manure to electricity, and in the case of Butler Farms, a sustainable hog farm produces enough electricity to power all farm operations.<sup>49</sup> As of 2012, 0.04% of livestock farms employed such biogas technology. Similarly, farms producing crops and trees can use crop waste in biomass gasifiers that heat biomass in an anoxic environment to produce gas that is then burned to power an electric turbine.

Geothermal energy is another distributed source, although it has less impact on electrification and is most often tapped for heating greenhouses, soils, and buildings.<sup>50</sup> Low-temperature geothermal systems that capture heat from soil 5-6 feet underground often have a 10-year payback period.<sup>51</sup> When coupled with other energy efficiency measures such as insulation, energy curtains, or optimizing airflow and filtration,

<sup>42</sup> US Department of Agriculture, *Solar Energy Use in US Agriculture Overview and Policy Issues*, 2011, [https://www.usda.gov/oce/reports/energy/Web\\_SolarEnergy\\_combined.pdf](https://www.usda.gov/oce/reports/energy/Web_SolarEnergy_combined.pdf).

<sup>43</sup> US Department of Agriculture, *Trends in US Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass*, 2016, [https://www.ers.usda.gov/webdocs/publications/74658/60128\\_eib159.pdf?v=42593](https://www.ers.usda.gov/webdocs/publications/74658/60128_eib159.pdf?v=42593).

<sup>44</sup> Union of Concerned Scientists, "Farming the Wind: Wind Power and Agriculture," 2003, <https://www.ucsusa.org/clean-energy/increase-renewable-energy/wind-power-agriculture>.

<sup>45</sup> The Center for Agriculture, Food and the Environment, *Renewable Energy Production on Farms*, University of Massachusetts Amhurst, 2009, <https://ag.umass.edu/crops-dairy-livestock-equine/fact-sheets/renewable-energy-production-on-farms>

<sup>46</sup> <https://www.ucsusa.org/clean-energy/increase-renewable-energy/wind-power-agriculture>.

<sup>47</sup> US Department of Agriculture, *Factors Affecting the Adoption of Wind & Solar Generating Systems on US Farms: Experiences at the State Level*, 2013, [https://www.06.usda.gov/oce/reports/energy/WindSolar\\_Web\\_08162013.pdf](https://www.06.usda.gov/oce/reports/energy/WindSolar_Web_08162013.pdf).

<sup>48</sup> US Department of Agriculture, *Trends in US Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass*.

<sup>49</sup> Aaron Larson, "Distributed Energy Award Goes to Unique Hog Farm Microgrid," *POWER*, 2019, <https://www.powermag.com/distributed-energy-award-goes-to-unique-hog-farm-microgrid/?pagenum=2>.

<sup>50</sup> Food and Agriculture Organization of the United Nations, *Uses of Geothermal Energy in Food and Agriculture*, 2015, <https://reliefweb.int/report/world/uses-geothermal-energy-food-and-agriculture#targetText=The%20case%20for%20geothermal&targetText=Agriculture%20both%20consumes%20energy%20and,significant%20savings%20to%20operating%20budgets>.

<sup>51</sup> Farm Energy, *Geothermal Heat for Greenhouses*, 2019, <https://farm-energy.extension.org/geothermal-heat-for-greenhouses/>.

geothermal payback periods can be further reduced. While the US has some of the best geothermal resources in the world, only about 10% of that potential is currently used.<sup>52</sup>

Finally, complementary technologies that tap into new smart devices can make distributed generation even more attractive for farmers and utilities alike. Smart inverters with increasingly simple plug-and-play design allow utilities to distribute power to local loads up to the rated capacity of the inverter, provide voltage support at the point of common coupling, and couple with advanced metering devices to supply control options based on near real-time electricity information.<sup>53</sup> DR technologies and energy storage, discussed in Sections 2 and 3, can also maximize the value of distributed generation.

## 4.2 Benefits of On-Farm Distributed Generation

The benefits of distributed generation for agricultural customers vary based on the technology and whether energy is generated for operations or for grid connectivity.

For farmers seeking to simply power their own operations, distributed generation can provide a source of power that requires minimal maintenance, is highly reliable, low cost, and provides energy independence. For utilities, off-grid resources can provide support in dealing with excess demand and seasonal fluctuations that an agricultural customer connected to the grid poses. For all parties involved, off-grid generation can help keep energy costs low, especially when installed in a location that would otherwise require costly transmission line extensions.

Growers who produce enough power to sell back to the grid have the added benefit of an additional source of income. With farm profits at a record 12-year low in 2018,<sup>54</sup> larger solar and wind installations represent a steady cash flow that can augment fluctuating crop prices. The potential is large—wind energy, for example, is predicted to create 80,000 jobs and \$1.2 billion in new income by 2020, according to the US Department of Energy.<sup>55</sup>

Biomass and biogas generation also holds the potential for increased income. Tripling biomass production is predicted to result in \$20 billion in income for farmers growing biomass crops.<sup>56</sup> Fast-growing native crops such as switchgrass and poplar are lower maintenance than many crops, require less water, fertilizer, and other inputs, and as a result, are cheaper to grown than many cash crops.<sup>57</sup> Unlike wind or solar, these technologies are not intermittent and can be produced and dispatched to meet demand.

Distributed generation provides many co-benefits to farmers. Solar has been shown to be beneficial when using the idea of solar sharing or agrivoltaics. This method of growing certain crops under the shade of solar panels allows farmers to produce electricity and crops from the same land, without detriment to the crops. In fact, leafy greens grown in the shade were found to have larger leaves, a response to the low-light environment.<sup>58</sup> This method of growing can also save water. A study from the University of Arizona

<sup>52</sup> International Renewable Energy Agency, *Renewable Energy Prospects: United States of America, REmap 2030 Analysis*, 2015, [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA\\_REmap\\_UAE\\_report\\_2015.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_REmap_UAE_report_2015.pdf).

<sup>53</sup> Navigant Research, *Communications Technologies for DER Integration*, 2018.

<sup>54</sup> Lee Smith, "The Top Global Trends Driving The Fourth Agricultural Revolution," Planet, 2018, <https://www.planet.com/pulse/top-global-trends-fourth-agricultural-revolution/>.

<sup>55</sup> Union of Concerned Scientists, "Renewable Energy and Agriculture: A Natural Fit," 2003, [https://www.ucsusa.org/clean\\_energy/smart-energy-solutions/increase-renewables/renewable-energy-and.html](https://www.ucsusa.org/clean_energy/smart-energy-solutions/increase-renewables/renewable-energy-and.html).

<sup>56</sup> Union of Concerned Scientists, "Renewable Energy and Agriculture: A Natural Fit."

<sup>57</sup> Union of Concerned Scientists, "Renewable Energy and Agriculture: A Natural Fit."

<sup>58</sup> Ecological Society of America, *Solar Panels Cast Shade on Agriculture in a Good Way*, 2019, <https://www.sciencedaily.com/releases/2019/07/190729123751.htm>.

found that growing jalapeños in areas shaded by solar produced the same amount of fruit as traditional growing methods but with 65 percent less transpired water loss.<sup>59</sup>

Increased renewable distributed generation can also reduce overall water costs. In 2010, over 45 percent of the country's water use went to nuclear and fossil fuel power plants.<sup>60</sup> The second-biggest use of water was for irrigation. In states increasingly concerned about drought and water shortage, water and energy are explicitly connected. Decreasing energy production from centralized power plants will directly benefit farmers, who are some of the hardest hit by rising water costs.

Distributed generation provides benefits to utilities as well. Agrivoltaics not only creates positive growing conditions and promotes dual land use, but also can increase the efficiency of the solar panels themselves.

Grid decarbonization is achieved as farmers install renewable energy and create carbon-neutral operations. Agricultural electrification through distributed generation is particularly valuable for states where in-state generation is required to meet renewable portfolio standards (such as Iowa) or states that give extra credit for in-state resources (such as Kansas). Additionally, the large landmass of farms in agricultural-rich states makes them one of the only sectors with the ability to become carbon negative.

Grid resilience increases as a result of distributed generation. Particularly in rural communities with limited access to resources and support during outage events, a resilient grid provides stability and peace of mind. However, these communities can also be the most susceptible to outages caused by old or faulty equipment and natural disasters. Long distances from central power generation, a lack of updated and redundant infrastructure, and lower community density cause resilience upgrades to often be expensive and time-consuming. Distributed generation, when connected to the grid, helps tackle this issue. Connecting these resources to the grid provides an impetus for transmission infrastructure updates, while the distributed nature of on-farm generation protects customers in the event of a weather event disrupting traditional centralized power service.

### 4.3 Challenges of On-Farm Distributed Generation

While on-farm generation provides energy independence and resilience against fluctuating energy prices for the farmer, it can pose an issue for utilities as they are replaced by isolated distributed generation systems. Agricultural customers are unique in that they often easily produce enough energy to entirely cover the energy needs of their operations. Unlike residential or other industrial customers who have a limited area to install distributed resources (and stay connected to the grid to cover power demand in peak periods), farms can install systems large enough to produce adequate power supply. In rural areas where extending a power line can be costly, there is even more incentive for growers to become their own power producers.

Grid-connected distributed generation also poses challenges for utilities if not properly planned for. Intermittent resources such as solar and wind may not always align with demand patterns, creating the potential for overproduction and system stress. Strategies to deal with an increasingly variable supply of energy are either expensive (storage) or not yet widely adopted (DR). The popularity of on-farm energy

<sup>59</sup> University of Arizona, "Farming Under Solar Panels Saves Water and Creates Energy," *Futurity*, 2019, <https://www.futurity.org/agrivoltaics-farming-solar-panels-2152772/>.

<sup>60</sup> Luciano Castillo, Walter Gutierrez, Jay Gore, "Renewable Energy Saves Water and Creates Jobs," *Scientific American*, 2018, <https://www.scientificamerican.com/article/renewable-energy-saves-water-and-creates-jobs/>.

production has led utilities in some states (such as Illinois) to limit the number of projects that will sell back to the grid.<sup>61</sup>

#### 4.4 The Future of Distributed Generation in Agriculture

The challenge for utilities is not convincing farms to install distributed generation, but rather to ensure those farms stay connected to the grid. This is important in areas where decreased net metering and tariffs are making grid-connected distributed generation less attractive.

Utilities can maximize the value of grid connectivity by offering and encouraging the use of utility-supported services such as DR that can help maximize the value of grid connectivity for customers. Similarly, onsite storage should be encouraged for customers looking to develop distributed resources. Other potential services include advanced monitoring and smart inverters that create a smart, communicative network and optimize the grid, so customers always select the best way to use their installed distributed resource (consume or sell). These technologies have the added benefit of augmenting the utility's capacity for flexible load management and, in some cases, allows the utility to coordinate dispatching for distributed sources effectively.<sup>62</sup>

Utilities that serve a high proportion of agricultural customers should take on-farm power generation into account during periods of resource planning. Agricultural customers are one of the only utility customers that can develop and use a variety of distributed resources. Unconstrained by land or rooftop area and with access to unique fuel sources (such as biogas) and storage options (such as water tanks), they have the potential to provide an entire suite of energy services to the grid. Once utilities understand their own resource needs, they can create programs that encourage resource development that aligns with those needs. For example, if overgeneration during the day is predicted, more resources should be allocated to distributed wind installation, which produces the majority of its energy at night.

Finally, utilities should leverage their space in the energy landscape to serve as a facilitator for solar providers, aggregators, and farmers to break out of their silos and understand each other's needs. Reducing the barriers to grid connectivity while ensuring the stability and resilience of the system will require cooperation amongst all entities.

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<sup>61</sup> Genevieve Bookwalter, "The Next Money Crop for Farmers: Solar Panels," *The Washington Post*, 2019, [https://www.washingtonpost.com/business/economy/the-next-money-crop-for-farmers-solar-panels/2019/02/22/2cf99e8c-3601-11e9-854a-7a14d7fec96a\\_story.html?noredirect=on](https://www.washingtonpost.com/business/economy/the-next-money-crop-for-farmers-solar-panels/2019/02/22/2cf99e8c-3601-11e9-854a-7a14d7fec96a_story.html?noredirect=on).

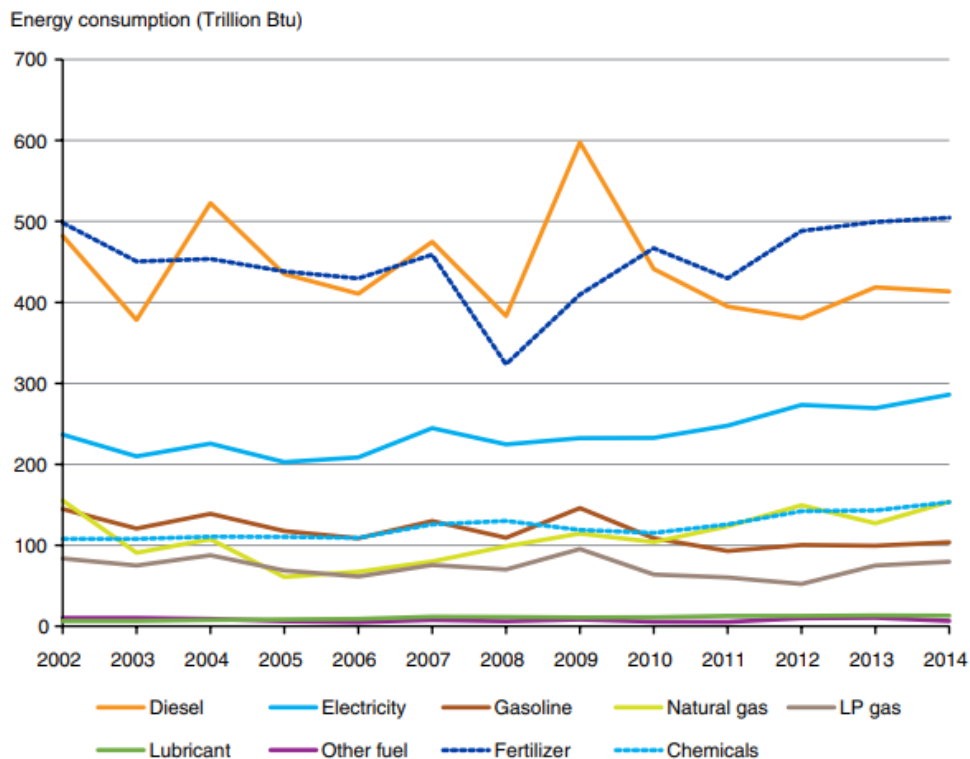
<sup>62</sup> Navigant Research, *Communications Technologies for DER Integration*, 2018.

## 5. FORECASTED ELECTRICITY GROWTH IN THE AGRICULTURE SECTOR

Limited data exists for electricity use in agriculture. Agriculture makes up a large percentage of electricity use in states where farming is prevalent; however, it is a small part of the overall energy use in the country and is not well studied. Most datasets group agriculture with industry, limiting insight.

The most recent analysis of trends in electricity use in agriculture is presented in Figure 3. Using expense data for farm operations from 2016 *National Agricultural Statistics Service Quick Stats 2.0* and EIA data from 2015, the US Department of Agriculture mapped trends in energy consumption from 2002 to 2014. This shows a steady increase in electricity from 2005 on. However, this data takes into account indirect energy consumption, such as that needed to produce fertilizer, so it cannot be interpreted as a clear indicator of the results of electrification.

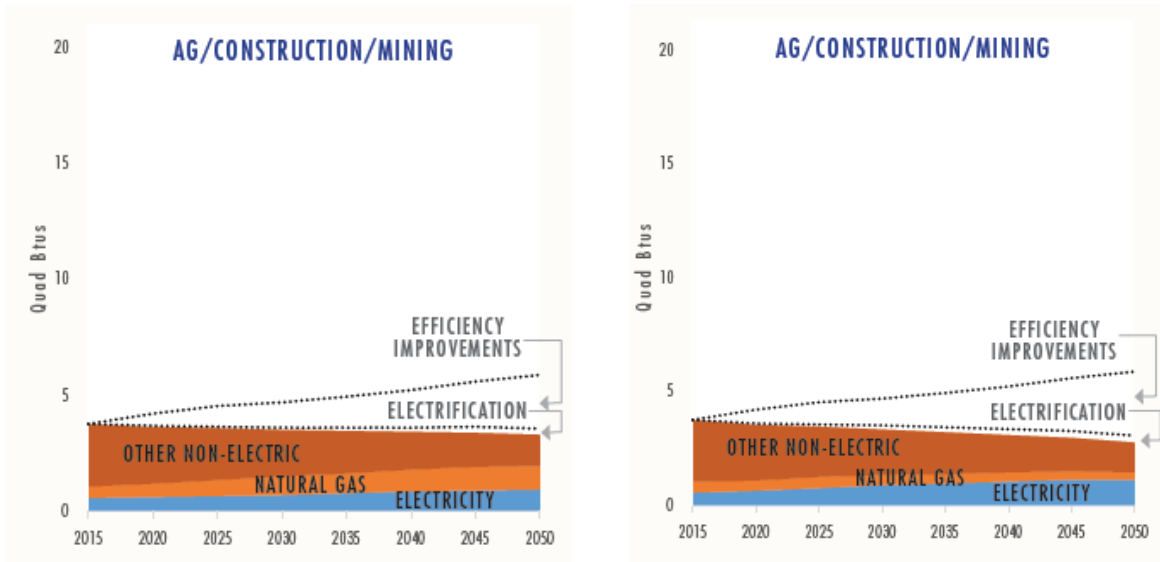
Figure 3. Direct and Indirect Energy Consumption by Fuel in the Agricultural Sector



Source: U.S. Department of Agriculture, *Trends in US Agriculture’s Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass*

Other studies forecast the total electricity use of different sectors as a result of electrification, but again, agriculture is not broken out. Figure 4 shows the effect of cheaper electricity replacing natural gas and petroleum. Battery technology improvements are also assumed in this scenario. While electrification minimally increases total electricity use in this forecast, it is substantially offset by energy efficiency gains.

**Figure 4. Business as Usual and Transformation Scenario for Industry Electrification**



Source: US National Electrification Assessment, Electric Power Research Institute